BEHAVIORAL MOMENTUM AND THE LAW OF EFFECT

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CONTENTS

Section		page
	Abstract	1
1	Introduction	3
	1.1 Response Strength	3
	1.2 Response Rate as a Measure of Response Strength	4
	1.3 Resistance to Change as a Measure of Response Strength	22
	1.4 Present Study	30
2	Experiment One	39
	2.1 Introduction	39
	2.2 Method	43
	2.3 Results	47
	2.4 Discussion	50
3	Experiment Two	54
	3.1 Introduction	54
	3.2 Method	58
	3.3 Results	60
	3.4 Discussion	68
4	Experiment Three	79
	4.1 Introduction	79
	4.2 Method	84
	4.3 Results	87
	4.4 Discussion	91
5	General Discussion	95
	Reference List	109
	Appendices	114

FIGURES

Figure		page
1.1	Catania and Reynolds (1968).	6
1.2	Catania (1963b).	9
1.3	Nevin (1974).	25
2.1	Proportion of Baseline Repone Rate. Change as a Function of Dark-Key Reinforcer Rate.	48
3.1	Absolute Respose Rate as a Function of Absolute Reinforcer Rate.	62
3.2	Proportion of Baseline Response Rate Change as a Function of Absolute Reinforcer Rate.	65
3.3	McDowell and Wood (1984) Reanalysed.	73
3.4	Davison (1988) Reanalysed.	75
4.1	Log Response Ratio as a Function of Log Reinforcer Ratio.	89

TABLES

Table		page
2.1	Experimental Conditions and Order of Condition Exposure in Experiment One.	45
3.1	Experimental Conditions and Order of Condition Exposure in Experiment Two.	60
3.2	Values of k and Ro in Experiment Two.	63
3.3	Proportion of Change in Hyperbolas.	67
4.1	Experimental Conditions and Order of Condition Exposure in Experiment Three.	86
4.2	Sensitivity and Bias Measures in Experiment three.	90
5.1	Mass Ratios in Experiments One and Two.	101
5.2	Conditions to Examine Combined Effect of Reinforcer Rate and Duration.	104

ABSTRACT

Two approaches to the study of response strength may be distinguished; one using the rate of responding as a measure of strength, and another using resistance of responding to change brought about by a new variable. Research in either tradition generally use quite similar methods of bringing about behavior change. The present group of studies aimed to investigate implications of the resistance-to-change findings for the response-reinforcer relationships studied in research on the Law of Effect. Experiment 1 showed that if reinforcers of different duration maintain responses in different multiple-schedule components, responding maintained by long reinforcers changes less when response-independent reinforcers are presented during an intervening blackout period. This greater resistance to change is still evident in steady-state responding, achieved after many sessions of training. Experiment 2 also used reinforcers of different duration in two multiple-schedule components. Instead of using reinforcers in blackout, responding was varied by changing the frequency of reinforcement maintaining responding in the two components. This time, the extent of response-rate change did not depend on the duration of the reinforcers maintaining responding. Response rates showed similar proportional changes in the two components when the rates of unequal-duration reinforcers were varied. Experiment 3 sought to determine whether the response rate ratio sensitivity to reinforcer rate ratios was greater when short duration reinforcers maintained responding than when long reinforcers

were used. Two identical series of reinforcer rate manipulations were used with two-component multiple schedules. A long reinforcer duration was used for both components in one series, and a short reinforcer duration was used in the other. Sensitivity to reinforcer rate ratios was essentially the same in the two series. The results of the three experiments show that the usual resistance-to-change findings may only occur when behavior change is brought about by a variable which is remote from the schedules maintaining responding. This inconsistency between the results of Experiment 1 and those of Experiments 2 and 3 may be due to differences in resistance to change being counterbalanced by unequal application of the assessment technique. Integration of the two approaches studying response strength is difficult because research has not fully investigated the possibility that aspects of the reinforcer situation may combine with one another.

INTRODUCTION

1.1 RESPONSE STRENGTH

Schedules of reinforcement provide powerful methods of controlling behavior. A major area of investigation has been an examination of the effect of reinforcement schedules on response 'strength'. There are two major views in the experimental analysis of behavior as to how response strength should be conceptualised. These two views have given rise to two largely independent lines of research. The longest established view has been in the Law of Effect tradition. With his puzzle boxes, Thorndike (1911) demonstrated a progressive strengthening of stimulus-response connection following reinforcement. For Thorndike, an animal's learning was no more than the strengthening of a response by the consequence of that response. The strengthening of behavior was displayed by a decrease in the time to escape a puzzle box; (i.e. an increase in the speed of the appropriate escape behavior). From these early studies grew the view that speed of responding is a measure of response strength. In free-operant procedures the speed of responding is measured in terms of a rate at which discrete operant behaviors occur.

A newer approach to investigating response strength has developed largely due to the efforts of J.A. Nevin and colleagues (e.g. Nevin, 1974; Nevin, Mandell & Attack, 1983). Their approach measures response strength as a proportional change in response rate following some change in reinforcer value. The resistance to change of a behavior is a measure of

its strength. Weak behavior is indicated by an easy disruption of response rate when reinforcement conditions are changed; whereas strong behavior is not so easily disrupted by the same change in reinforcement conditions. The present study takes these two independent views of response strength and attempts to integrate them.

1.2 RESPONSE RATE AS A MEASURE OF RESPONSE STRENGTH

Herrnstein (1970) reasoned that the degree to which reinforcement affects the strength of behavior is reflected in response rates. Increases in the maintaining reinforcer rate typically increase the response rate, and therefore, responding is said to be strengthened. Decreases in the maintaining reinforcer rate typically decrease the response rate, and therefore, responding is said to be weakened. By taking response rate as a measure of response strength researchers have been able to investigate the Law of Effect in a quantitative manner. Three main relationships have been investigated: absolute response rates versus absolute reinforcer rates; absolute response rates versus reinforcement for 'other' behavior; and, relative reinforcer rates versus relative response rates. Each of these relationships will be discussed below.

1.2.1 Absolute Response Rates Versus Absolute Reinforcer Rates

An overall rate is the number of events (either reinforcers or responses) divided by the total session time (Catania & Reynolds, 1968; and Davison & McCarthy, 1988). Catania and Reynolds (1968) quantitatively investigated the relation between overall rate of key-pecking and overall rate of reinforcement maintained by single variable-interval (VI) schedules. Overall reinforcer rates varied from 8.4 to 300 reinforcers per hour. For each of the six pigeons the overall rate of key-pecking increased as the the reinforcer rate did. The functions relating reinforcer rate to the rate of responding were monotonic and negatively accelerating. The relations were therefore well described by a hyperbolic function with many appearing to reach an asymptotic level at the higher levels of reinforcement.

The hyperbolic relationship between response and reinforcer rates has been found across species and reinforcement conditions. For example, the data of Davenport, Goodrich and Hagguist (1966) indicated that on a single schedule primate behavior displays the same hyperbolic relationship. McDowell and Wood (1984) used humans on five single VI schedules. The reinforcers within each schedule ranged from .25 to 35 cents. For each reinforcer magnitude the relationship between absolute response and absolute reinforcer rates was examined. The results indicated that while some parameters of each hyperbola increased with higher reinforcer magnitude the hyperbolic function itself fitted the data very well. Similar results to those of McDowell and Wood

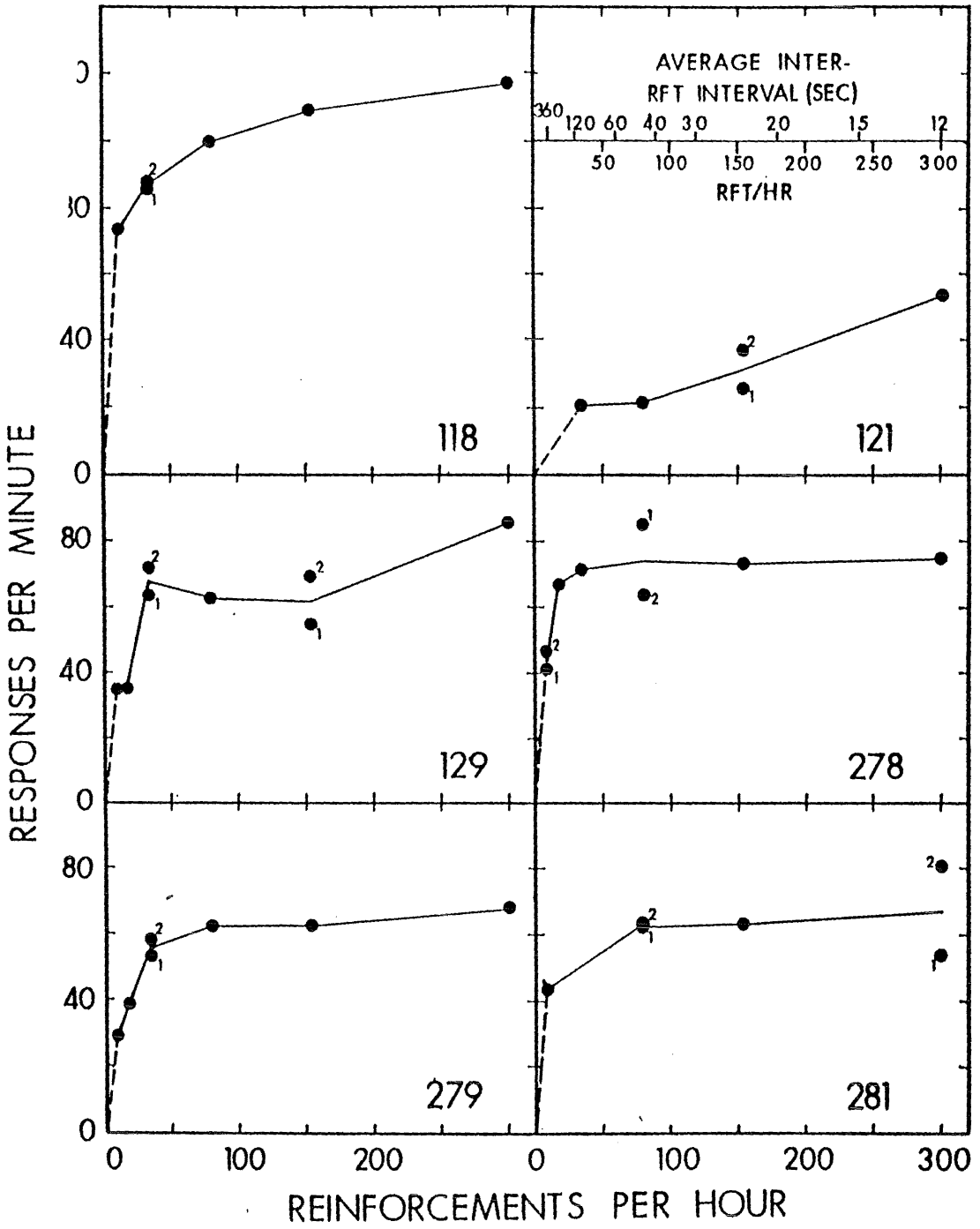

FIG 1.1. Rate of key pecking (responses per minute) as a function of the reinforcer rate (reinforcers per hour) for six pigeons. The graphs are from Catania and Reynolds (1968, p 331). Each point is the mean of the response rates over the last five sessions of a given schedule.

were obtained by Bradshaw, Szabadi and Bevan (1978). Bradshaw et al used rats as subjects and varied the reinforcer rate across different levels of sucrose concentration. As sucrose concentration (reinforcer magnitude) increased so did the asymptote in the hyperbolic functions.

The hyperbolic relationship that was found to exist between absolute response and reinforcer rates in single VI schedules can also be demonstrated to occur when more than one schedule of reinforcement is made available in a session. The concurrent-schedules procedure arranges for two or more alternative schedules to be available simultaneously. The subject then allocates its responses across alternatives. The multiple-schedule procedure presents different schedules successively across time. The discriminatively signaled periods of time are called components. The hyperbolic relationship emerges between response rates and increasing reinforcer rate for one alternative in a concurrent schedule (Catania, 1963). Likewise, the hyperbolic relationship emerges between responding and increasing reinforcer rate in one component of a multiple schedule (Reynolds, 1961b).

In general it appears that the hyperbolic function relating absolute reinforcer and response rates is robust across species, procedures and reinforcement conditions, (see de Villiers & Herrnstein, 1976; de Villiers, 1977; and Davison & McCarthy, 1988 for reviews).

1.2.2 Reinforcer Rate Versus Other Reinforcers

To study reinforcer interaction requires procedures that make two or more schedules of reinforcement available in a single session. For this reason concurrent- and multiple-schedule procedures have been typically employed. Studies employing concurrent- and multiple-schedule procedures have generally presented different reinforcer rates across alternatives and components, respectively. Given that behavior for one alternative (in a concurrent procedure) or for one component (in a multiple procedure) increases in a hyperbolic manner with increasing reinforcer rate an important question is, 'what happens to behavior associated with the other alternative(s) or component(s) if the reinforcer rate for it is constant'?

Catania (1963, Experiment 1) presented a series of conditions using the Findley concurrent reinforcement procedure. In the Findely procedure (Findley, 1958) two operandum are available simultaneously to the subject. Responses on one operandum switch the discriminative stimuli on the main response operandum. By changing the stimulus on the main response operandum the subject is able to choose which schedule of reinforcement is being responded to. In Catania's study the VI schedule on a red key stimulus was varied over conditions between 0 and 40 reinforcers per hour. The VI schedule on the alternative yellow key stimulus always arranged 20 reinforcers per hour. Catania found that responses in the varied schedule (red) increased monotonically with an increase in reinforcers delivered in that alternative.

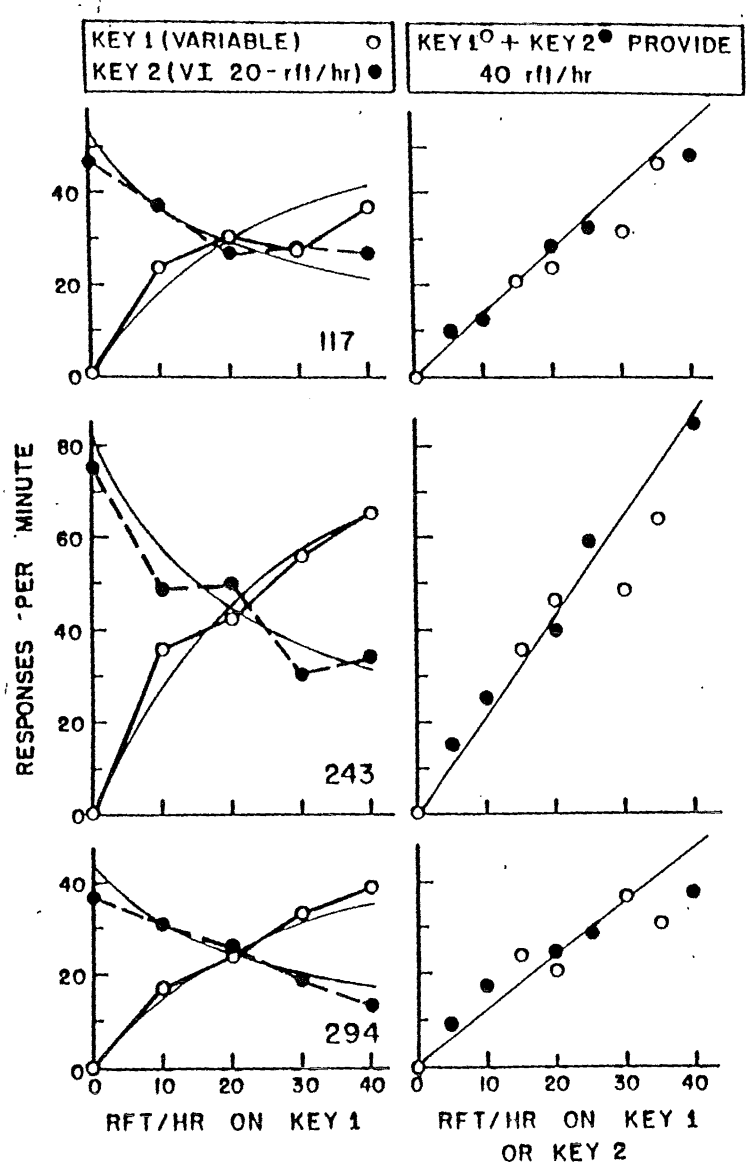

FIG 1.2. Rate of responding (responses per minute) on each key in a concurrent schedule as a function of the reinforcer rates (reinforcers per hour). The smooth curves on the left hand graphs were generated from a theoretical equation. The graphs are from Catania (1963, p 257).

Responding in the constant schedule (yellow) changed also. With increasing reinforcement in the red schedule, responding in the yellow schedule decreased. In fact the rate of responding in the yellow stimulus varied in an inverse manner

to that in the red stimulus.

The effect observed by Catania (1963) can be considered a result of 'reinforcer interaction'. The effect that a particular schedule of reinforcement has on maintained behavior is influenced by schedules of reinforcement concurrently available to the organism. The interaction in Catania's study appeared to be orderly in that the functions relating changes in reinforcer rate for red to responding in yellow were smooth and the inverse of the function relating reinforcer rate in red to response rate in red.

An interaction, similar to that demonstrated in concurrent schedules has been observed in multiple schedules and is called Behavioral Contrast (Reynolds, 1961b) . Contrast in multiple schedules occurs if the response rates in the two components change in opposite directions even though only one of the reinforcement schedules is changed. Positive contrast is an increase in responding in an unchanged component when reinforcer conditions worsen in the changed component. Negative contrast is a decrease in the response rate of the constant component when the changed component is made richer.

Reynolds (1961b) demonstrated that if, after establishing a steady response rate on two keys, the VI schedule in one component was changed to extinction while the other remained constant, the response rate in the constant component rose by approximately 50% of it's baseline level. Reynolds (1961a) found that timeout and extinction in one component caused contrast in the other component. However, it was also demonstrated that if reinforcement was maintained without

responses being required in the changed component (i.e. via a DRO procedure) then no contrast was observed. This result indicated that contrast effects are a result of a change in the reinforcement conditions rather than a change in the response requirements, (see Williams, 1983 for an extended review).

Multiple schedules with three components have also been investigated. Nevin and Shettleworth (1966) observed positive behavioral contrast in a component maintained by a constant VI 10-min schedule when a VI 1-min schedule was alternated with an extinction schedule as the preceding component.

The presence of reinforcer interaction in concurrent schedules indicates that the response rate in the presence of a given stimulus is determined by the frequency of reinforcement across all the stimuli that concurrently control a subjects' behavior. Likewise, in multiple schedules, it appears that the response rate in the presence of a given stimulus is determined by the frequency of reinforcement during all of the stimuli that successively control a subjects behavior. (See, however, McLean & White, 1983; and McLean, 1988 for an alternative interpretation).

1.2.3 Relative Response Rate Versus Relative Reinforcer Rate

Herrnstein (1961) arranged a series of concurrent VI VI schedule conditions using a two-key concurrent-schedule procedure. In this procedure, two operanda are available to the subject. Responses on these are reinforced according to

variable-interval schedules. Each condition was in effect for a number of conditions to ensure that behavior was stable, (i.e. showed little deviation in response rates from session to session). Across conditions the two reinforcer rates were varied but overall reinforcer rates were maintained at 40 reinforcers per hour. Herrnstein naturally found that the subjects preferred the higher reinforcer rate. Herrnstein also found that relative response rates approximately equaled (or 'matched') relative reinforcer frequency for the two alternatives:

$$\frac{R1}{R1 + R2} = \frac{B1}{B1 + B2} \qquad \text{Equation 1}$$

In Equation 1, *R* is the reinforcer rate, *B* is the response rate and subscripts denote the two alternatives. This relationship has come to be known as the 'matching equation' (Baum, 1974, 1979; de Villiers, 1977), or the 'strict matching equation' (Davison and McCarthy, 1988).

Reynolds (1963) conducted three experiments using multiple schedules. In the first experiment the VI schedule in one component was varied and the other was maintained at VI 180-sec. In the second experiment both VI schedules were varied. Reynold's data displayed a relation between relative component response rates and relative reinforcer rates, even when both components were varied. However, the function relating relative response and reinforcer rates shows a deviation from the straight line function displayed by concurrent schedules. The function for multiple schedules was flatter at the less extreme proportions. Such a relationship

suggests that subjects on a multiple schedule 'undermatch' their behavior to the proportion of reinforcers across the components (Fantino, Squires, Delbruck and Paterson, 1972). That is, in multiple schedules subjects distribute their responses more evenly across components than in concurrent schedules.

Staddon (1968) found the form of Equation one inadequate when applied to data he obtained investigating response allocation using concurrent differential reinforcement of low response rates (DRL). He noted that Equation one did not display the regularities present in his data. Staddon applied the following relation to the data:

$$\frac{B1}{B2} = \frac{R1}{R2} \qquad \text{Equation 2}$$

The symbols in Equation 2 are the same as those in Equation 1.

To test the applicability of Equation 2 Staddon graphed the log of B1/B2 as a function of R1/R2. A line fitted to such data has the equation:

$$\log(B1/B2) = a \log(R1/R2) + \log(c) \qquad \text{Equation 3}$$

Equation 3 describes a straight line relation between log reinforcer and log response ratios, where *a* = slope and *log(c)* = *y* axis intercept. These values are arrived at empirically from the plotted data (Baum, 1974). Staddon found that Equation 3 with *a* = .66 and *c* = .24 described his data.

By exponentiating both sides, Equation 3 becomes:

$$\frac{B1}{B2} = c \left(\frac{R1}{R2}\right)^{a} \qquad \text{Equation 4}$$

Equations 3 and 4 have come to be known as the generalised matching equations (Baum, 1974; de Villiers, 1977; and Davison & McCarthy, 1988). Equation 4 reduces to Equation 2 and, hence, to Equation 1 when *c* and *a* both equal one. Therefore, the strict matching relationships observed in data of Herrnstein (1961) and Catania (1963b) may be considered special cases of the more general relationship described by Equations 3 and 4 (Baum, 1974). Baum (1974) noted that individuals may display values of *a* greater or less than one, therefore in a single concurrent schedule experiment the average slope may be $a=1$; this would result in strict matching being obtained. Typically, the values of *a* vary between .75 and 1.0 (Baum, 1979).

Equation 4 also provides an accurate description of multiple-schedule performance. For a multiple schedule B1, B2 and R1, R2 represent response and reinforcer rates (respectivel) across different components (1 and 2). When plotted on log ratio co-ordinates multiple-schedule data displays a straight line function relating reinforcer and response ratios with a value for *a* between .3 and .6 (Lander and Irwin, 1968; Charman & Davison, 1982; and McLean and White, 1983).

The parameters *c* and *a* represent two types of deviation from strict matching. The slope of the matching line on log

co-ordinates (*a*) provides a measure of sensitivity to reinforcement rate ratios. When $a < 1.0$ then a subject is distributing responses more evenly between response operandum than is predicted by strict matching. Values of $a < 1.0$ have been termed 'undermatching' by Baum (1974).

A number of factors have been investigated as sources of variation in reinforcer sensitivity. For instance, Baum (1979) reasoned that in a concurrent schedule subjects tend to change over after the delivery of a reinforcer. When this happens more time will tend to be allocated to the leaner schedule than is predicted by strict matching. Alsop and Elliffe (1988) varied the reinforcer rate ratio in a concurrent schedule. They also varied the overall rate of reinforcer delivery. They found that the obtained values of *a* decreased as the overall reinforcer rate decreased. Todorov, Oliveira-Castro, Bittencourt de Sa and Barreto (1983) demonstrated that the number of training conditions received affects sensitvity. As the number of conditions increased, the estimates of *a* decreased.

The y-intercept of Equation 4 on log co-ordinates (*c*) provides a measure of bias towards responding on one operandum over another. This measure of bias reflects unnaccounted for preference in the experimental situation (Baum, 1974). Experiments arranging constant inequalities across experimental conditions in which an independant variable is manipulated show the effects of bias on matching. For example, Davison and Ferguson (1978) presented pigeons with the alternative of lever pressing or key pecking on a concurrent schedule. The ratio of reinforcers on each

operandum was varied across conditions. Subjects showed a bias towards key pecking.

1.2.4 Statements of the Law of Effect.

A number of quantitative models have been proposed which attempt to account for the three types of behavioral phenomena discussed above. The most influential of these models has been a series of equations set forth by Herrnstein (1970, 1974). Herrnstein's concurrent schedule analysis measured the strength of one response in terms of the relation between response rate and all concurrently available reinforcers:

$$B1 = \frac{k \cdot R1}{(R1+R2+Ro)} \qquad \text{Equation 6a)}$$

and for responding in the alternative schedule:

$$B2 = \frac{k \cdot R2}{(R1+R2+Ro)} \qquad \text{Equation 6b)}$$

In Equation 6, B1, B2, R1, and R2 are defined as above; *k* and Ro are derived empirically. The interpretation of Ro is extraneous reinforcement obtained from sources other than R1 and R2. Ro supports behavior that is unmeasured in the experimental setting (Bo). Examples of such behavior are preening and scratching. Herrnstein assumed that Ro would be constant with changes in the response parameters. The parameter *k* is a value that is derived from the asymptotic

level of the hyperbolic function. According to Herrnstein this asymptotic level reflects the total amount of behavior that occurs in an experimental session. Therefore, *k* is equal to B1+B2+Bo, all measured in the same units. Herrnstein (1974) assumed that since *k* reflected the total amount of behavior possible, it must be invariant with variations in the reinforcer parameters. For example, *k* should be invariant with changes in the total amount of reinforcement.

For a single VI schedule Equation 6 can be written:

$$B1 = \frac{k \cdot R1}{R1+Ro} \qquad \text{Equation 7}$$

Equation 7 describes a hyberbolic function with two constant terms. Such a function can be made to fit the data obtained from single schedules (e.g. Catania and Reynolds, 1968). Herrnstein fitted Equation 7 to Catania and Reynolds data and for all six pigeons very good fits were obtained.

Equation 6 also accounts for reinforcer interaction in concurrent schedules. As there is only a fixed amount of behavior available for a subject (*k*), an increase in R2 decreases the denominator of Equation 6a and reduces predicted P1.

Equations 6 and 7 assume strict matching. If *k* is substituted by B1+Bo in Equation 7 then:

$$B1 = \frac{(B1+Bo) + R1}{R1 + Ro} \qquad \text{becomes} \qquad \frac{B1}{B1 + Bo} = \frac{R1}{R1 + Ro}$$

de Villiers (1977) reviewed a number of studies and

noted that the vast majority of subjects' data was accounted for by Herrnstein's matching equation. However, because Herrnstein's analysis assumes strict matching, (*a* and *c* equal to one), inaccuracies in the empirical estimates of *k* and Ro must result from the confounding influence of undermatching and bias (McLean and White, 1983). For instance, White, McLean and Aldiss (1986) examined lever pressing in rats using a concurrent-schedule procedure. They found that estimates of Ro for right lever pressing performance did not bear a direct relation to the 'extraneous' reinforcers gained from the left lever. They noted that such instances were not accounted for by Herrnstein's equation unless undermatching and bias were taken into account via a generalised matching analysis.

Herrnstein (1970) extended his analysis to multiple-schedule performance. Herrnstein noted that as components in a multiple schedule become more separate from one another (e.g. slow component alternation) the interactions between components can be expected to diminish. Herrnstein introduced the parameter *m* into Equation 6 to describe the degree of component interaction:

$$B1 = \frac{k \cdot R1}{R1+mR2+Ro} \qquad \text{Equation 8a)}$$

and for responding in the other component-

$$B2 = \frac{k \cdot R2}{R2+mR1+Ro} \qquad \text{Equation 8b)}$$

The value of *m* lies between 1.0 and zero. *m* = 1

indicates maximal interaction between the components as is the case for alternatives in a concurrent schedule. $m = 0$ indicates no interaction between components. For any value of $m < 1.0$ undermatching of relative reinforcer and response rates occurs.

There are a number of problems with Equation 8. An important aspect of Equation 8 is that it predicts Behavioral Contrast. According to Equation 8, if reinforcement in Component two is decreased and $m > 0$ then the behavior in Component one will now increase because mR2 is now exerting less influence in reducing P1. Spealman and Gollub (1974) noted that Equation 8 also made a prediction about the magnitude of contrast. Assuming constant values for m and Ro over equal components then Equation 8 predicts that as the value of R1 increases so will the magnitude of contrast in the unchanged component, (measured by % rate change). They found the opposite relationship. The magnitude of contrast in the unchanged component was inversely related to reinforcer frequency in the changed component.

Equation 8 fails to predict changes in contrast that occur when Ro is varied. With larger values of Ro, Equation 8 predicts smaller contrast in R1 when R2 is varied. Hinson and Staddon (1978) obtained larger contrast in rats when Ro was analysed with a running wheel present than when it was not arranged.

The introduction of the m parameter creates a logical inconsistency in Herrnstein's formulations (Davison & McCarthy, 1988; and McLean & White, 1983). The source of the problem lies in the fact that k is a constant representing

total amount of behavior. Taking Bo1 as the amount of extraneous behavior in component one expands Equation 8 to:

$$Bo1 = \frac{k \cdot Ro1}{R1+mR2+Ro1+mRo2}$$

Adding B1 and Bo1 should according to Herrnstein's assumptions yield a value of *k*. However, if the equations for B1 and Bo1 are added the result does not equal *k* for values of $m > 0$ (Davison and McCarthy, 1988). Using the same logic, it is possible to show that even if *k* is assumed to be constant across both components, B1+Bo1+B2+Bo2 does not sum to *k* for values of $m < 1.0$.

Catania (1973) proposed an alternative set of equations for response strength which make very similar empirical predictions to those of Herrnstein's. Catania assumed that responding increases in a linear fashion with an increase in reinforcer rate. Interacting with this effect is inhibition from the total reinforcers present for that response:

$$B1 = \frac{K \cdot C \cdot R1}{C + \Sigma R} \qquad \text{Equation 9}$$

In Equation 9, *C* is a constant that depends on a reinforcers inhibitory effects. ΣR is equal to the sum of all specified reinforcers; (therefore it doesn't include extraneous reinforcers as in Herrnstein's equations). *K* is a constant which when multiplied with R1 equals B1, if no inhibition were present. Therefore, *K* describes the linear relationship between R1 and B1. Resetting $K \cdot C$ to a new constant called *k* yields:

$$B1 = \frac{k \cdot R1}{C + \sum R} \qquad \text{Equation 10}$$

k and *C* can now be obtained empirically in the same fashion as the free parameters in Equations 6 and 7 were. Catania also extended the equations to concurrent- and multiple-schedule performance. de Villiers (1977) noted that Catania's equation accounts for as much of the data as does Herrnstein's. Likewise, Catania's equations fall prey to many of the same problems as Herrnstein's. Catania assumed that *k* in Equation 10 is constant except for changes in the units of measurement. Catania's *k*, like Herrnstein's *k*, should not change with changes in the reinforcer parameters. For both authors, *k* desribes the the asymptotic level of responding. However, the constancy of *k* has not found empirical support. For example, McDowell and Wood (1984) presented human subjects with a range of single VI schedules. The VI schedules were repeated across a range of reinforcer magnitudes. As noted in Section 1.2.1 a hyperbolic relationship fitted the data at each magnitude. However, the derived value of *k* increased with increasing reinforcer magnitude. That is, *k* changed with changes in the reinforcer parameters, a relationship which is not predicted by either Herrnstein or Catania.

McDowell (1986) argued that Herrnstein's equations can be tested with no functional asssumptions. For instance, if the requirement that *k* remain constant with the change in reinforcer rate is ignored then the finding of a variable value of *k* is not a problem. However, eliminating such assumptions leads to a problem in interpretation. If the

parameters in an equation which purports to describe behavior have little or no psychological significance then the utility of the equation is questionable. Likewise, a problem with the generalised matching accounts of matching is that they entail at least two free parameters (i.e. parameters obtained by fitting the data to an existing equation). The bias and sensitvity parameters in Equation 4 effectively 'soak up' deviations from strict matching. However, the variables which effect them are poorly understood (Baum, 1974, 1979). It is questionable how psychologically valid such parameters are.

The theories reviewed above are all statements of the Law of Effect. They measure response strength by examining response rates. The theories themselves are descriptively impressive having been based upon the empirical data itself. However, they all share problems at the theoretical level.

1.3 RESISTANCE TO CHANGE AS A MEASURE OF RESPONSE STRENGTH

1.3.1 The Partial Reinforcement Effect

An alternative approach to examing response strength in terms of response rate is to examine response strength in terms of behavior's resistance to change. When behavior is easily disrupted or altered by a change in the reinforcement conditions then it can be labelled weak behavior. When behavior is resistant to disruption by changes in the reinforcement conditions then that particular behavior can be labelled as strong.

A historical precedent to examining response strength in terms of resistance to change was set by studies examining the Partial Reinforcement Effect (e.g. Humphreys, 1939). The partial reinforcement effect (PRE) can be demonstrated by taking two groups of subjects. One group is exposed to continuous reinforcement (i.e. a reinforcer is gained for every response made) while reinforcers for the other group are delivered intermittently (e.g. VI 10-min). After experience on the schedule both groups are transferred to an extinction schedule. A general finding is that responding decreases more rapidly in a change from continuous reinforcement to extinction than from intermittent reinforcement to extinction. Behavior which is more frequently reinforced appears to be less resistant to a change in the reinforcement conditions. Intermittent reinforcement appears to result in behavior that is 'stronger' than more frequently reinforced behavior.

The PRE seems paradoxical when compared with the basic notion underlying the Law of Effect. All the research examined in previous sections demonstrated that as a reinforcer rate increased so did the corresponding response rate. Since these studies used response rate as a measure of response strength, these results indicated that frequently reinforced behavior was stronger than infrequently reinforced behavior. At face value, the two conceptions of response strength seem to be incompatible.

The inconsistency between the Law of Effect studies and the PRE is resolved when the PRE is re-examined in terms of Behavioral Momentum Theory (Nevin, Mandell & Attak, 1983; and Nevin, 1988). The discussion now turns to research examining

resistance to change and the theory which has come from this.

1.3.2 Resistance-to-Change Research

The PRE is part of the more general phenomenon of respondings' resistance to change in the reinforcer conditions. Manipulations other than changing the reinforcer schedule to extinction (e.g. response-independent food) alter response rates as a function of the baseline reinforcer conditions. Nevin (1974) conducted a series of experiments which demonstrated the effect of 'disruption' on behavior established in each component of a multiple schedule. Experiment one explored changes in responding in a three-component multiple schedule. Key pecking was reinforced on a VI scedule at 60 reinforcers per hour on a green key and 20 reinforcers per hour on a red key. The frequency of response-independent food was varied in the third component across conditions. In the third component no key stimuli were were present. In this procedure response-independent food delivered between the other two components can be thought of as a change in or disruption to the reinforcement conditions. Baseline response rates for each component were established in a condition in which no response-independent food was presented during the third component. Over successive conditions, the rate of response-independent food was varied. Between each change in the frequency of response-independent food delivery, baseline conditions were reinstated.

The relative response rates in Figure 1.3 provide a measure of the resistance to a change in the reinforcement

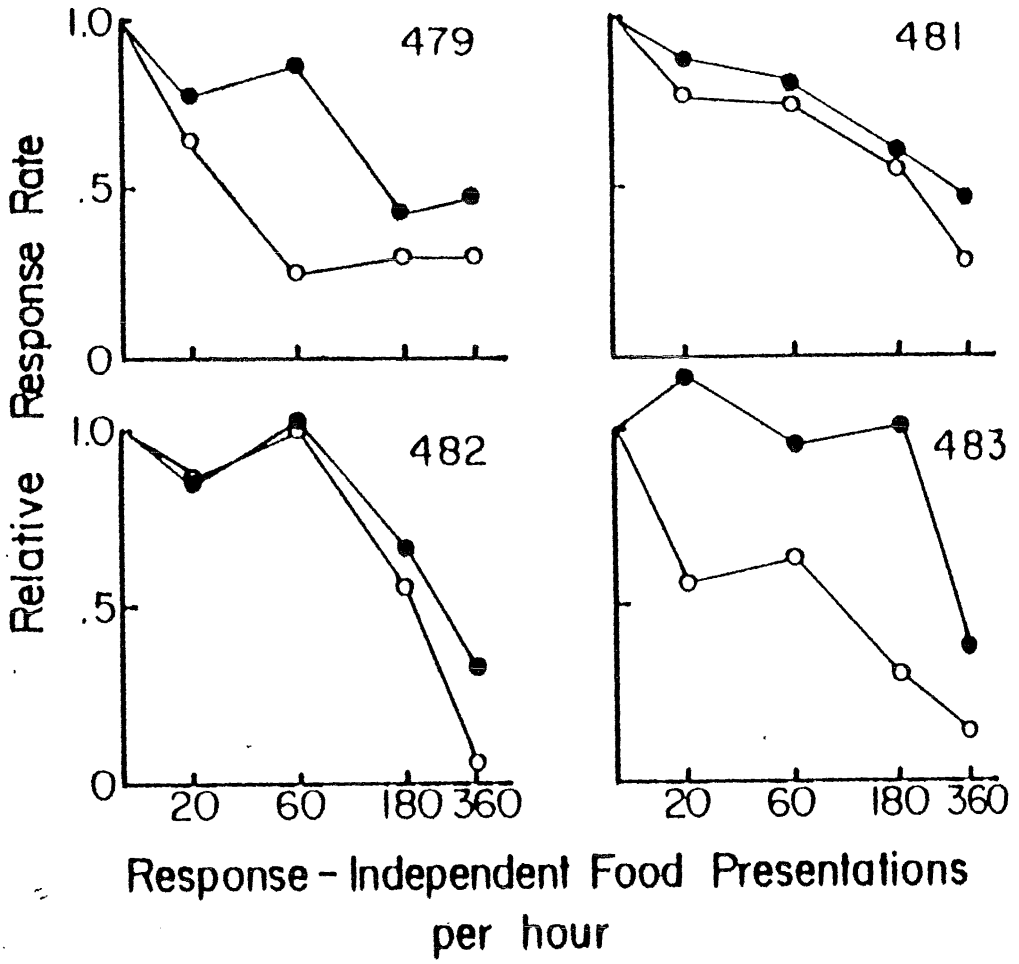

FIG 1.3. The vertical axis shows the rate of responding to a green key (filled circles), maintained by VI 1-min reinforcement, or to a red key (unfilled circles), maintained by with a VI 3-min schedule, relative to baseline rates of responding in green or red respectively. On the horizontal axis the frequency of response independent food is shown. The graphs are from Nevin (1974, p 392).

conditions for each component in Nevin's procedure. The relative response rates were obtained by expressing the rate of responding during the first session of a response-independent food condition as a proportion of the

baseline rate from the immediately preceding three sessions. The closer the relative response rate is to 1.0 the less it has changed as a proportion of baseline. The results from this experiment demonstrated that responding maintained by the higher reinforcer frequency (green key) changed less as a proportion of baseline than responding maintained by the lower reinforcer frequency. That is, responding that was more frequently reinforced was more resistant to change (therefore stronger) than less frequently reinforced behavior.

Reinforcer rate is not the only dependent variable that has been examined in terms of resistance to change. Nevin (1974, Experiments 3 and 4) demonstrated that reinforcer duration and delay had effects on resistance to change that are consistent with those of reinforcer rate. Specifically, the longer the reinforcer duration or the shorter the reinforcer delay, the greater is the resistance to disruption from response-independent food.

A variety of techniques apart from response-independent food have been used to assess resistance to change, (e.g. changing the reinforcer schedules to extinction, Nevin, 1974 Experiment 2; and prefeeding before a session, Eckerman, 1968 cited in Nevin, 1979). Whatever the assessment technique used there are a number of general features that studies examining resistance to change possess. Each study began by establishing stable baseline response rates. Following this a 'disruptor' is introduced by producing some change relating to the reinforcement conditions. In the case of extinction as an assessment technique, the disruption is the total removal of arranged reinforcers. In this respect the procedure is very

similar to the procedure used to investigate the PRE. Resistance to change is subsequently assessed by calculating the change in response rate as a proportion of baseline responding. Ordinal comparisons can then be made by comparing performance across the components of a multiple schedule. The general finding is that the greater the reinforcement is for behavior the more resistant to change it is (Nevin, 1974; Nevin, 1979; Nevin, Mandell & Attak, 1983; and Nevin, 1988). This finding is contrary to the PRE, which indicates that a lower reinforcer rate results in responding that is more resistant to change.

1.3.3 Behavioral Momentum Theory

Although the absolute change in responding tends to be greater for more highly reinforced behavior, it is that change expressed as a proportion of baseline that is important in assessing resistance to change. Nevin (1974, Experiment 5) demonstrated that resistance to change was independent of the baseline response rates. Nevin established low rates of responding in a VI 1-min component using a DRL procedure and high rates in a VI 3-min component using DRH. Absolute levels of responding in the richer DRL schedule were now lower than those in the leaner DRH schedule. However, responding in the richer component still displayed greater resistance to change. This result was replicated by Fath, Fields, Malott and Grossett (1983). Fath et al presented dark-key food as a disruptor of behavior. The reinforcer rate on both schedules

was identical. However, response rates across components were made uneven by employing DRL and DRH requirements. Regardless of the duration of response-independent food, the response rates in both components changed by the same proportion of their baseline levels.

The indication that maintained response rate and resistance to change may be separate aspects of behavior led Nevin, Mandell and Attak (1983) to develop Behavioral Momentum Theory. Nevin et al noted that in classical Mechanics, momentum is defined as the product of the mass and velocity of a moving object. When force is applied to a moving object, the object decelerates in proportion to the product of the force applied to it and the inverse of its own mass:

$$Vo - Vf_x = f_x / m \qquad \text{Equation 11}$$

In Equation 11, Vo = initial velocity, Vf_x = velocity after a force of value x is applied; and m = mass.

If the baseline response rates under constant reinforcer conditions are considered analogous to initial velocity, and a disruptor (such as response-independent food) is thought of as an external force, then, the change in response rate is inversely proportional to the behavioral mass:

$$(Bo - B_x) / Bo = x / m \qquad \text{Equation 12}$$

In Equation 12, Bo = initial response rate; B_x = response rate after force of value x applied; m = behavioral mass. $(Bo - B_x) / Bo$ gives a value for resistance to change by measuring

the change in response rate (Bo-B*x*) relative to a baseline response rate (Bo).

Both sides of Equation 12 are dimensionless. That is, *x* and *m* are measured in the same units. However, the units for *x* (and hence *m*) vary depending on the nature of the force used (prefeeding, extinction, dark-key food etc). Consequently, there can be no consistent units of measurement for *m*. Therefore, to determine the conditions which result in higher mass (and thereby produce 'stronger' behavior) only ordinal comparisons can be made by comparing two or more performances. For this reason multiple- and concurrent-schedule procedures must be used to allow comparison.

Nevin (1974, Experiment 5) and Fath et al (1983) demonstrated that of the value of Bo (initial behavioral velocity), it is the proportion of change in behavioral velocity ((Bo - B*x*) / Bo) that provides a measure of behavioral mass. Viewed in terms of Behavioral Momentum Theory, Nevin's result when response-independent food was presented (Nevin, 1974 Experiment two) shows that the higher rate of reinforcement established behavior with the greater mass. The mass of behavior dictates it's resistance to change. Given that strong behavior is resistant to change, strong behavior must also possess greater mass. Consequently, research investigating resistance to change indicates that, the greater the reinforcement, the stronger (or more resistant to change) is the behavior. This conclusion is the same as that reached by the Law of Effect research, and is the relationship described by Herrnstein's equations.

So how to reconcile the present conclusions with the PRE?

Nevin (1988) reanalysed a number of studies in which the PRE had been reported. Nevin noted that the usual measure in these studies was to take total number of responses emitted during the presence of extinction. Reanalysed in terms of proportion of baseline responding, these studies often showed that free operant behavior correlated with continuous reinforcement (the high reinforcer rate) was more resistant to extinction than intermittently reinforced (the low reinforcer rate) behavior. Thus the data presented in support of the PRE often seems consistent with the conclusions drawn from both the Law of Effect resistance-to-change research.

To summarise, the Law of Effect and resistance to change studies both demonstrate that the higher the rate of reinforcement the stronger is behavior maintained by reinforcement. The present study examines some of the implications of Behavioral Momentum Theory for the relationships between reinforcers and responding examined by Law of Effect studies.

1.4 THE PRESENT STUDY

1.4.1 Summary

In his influential paper 'On the Law of Effect', Herrnstein (1970) claimed to be looking at response strength. Herrnstein referred to response strength as steady-state response allocation across behavioral alternatives. Response allocation was measured by response rates for the

alternatives. The greater the level of reinforcement for an alternative the higher the response rate on that alternative relative to other alternatives.

The notion of response strength supported by Nevin and colleagues emphasises that response strength can be measured by a comparison of behavior established under one condition against subsequent performance following some change in that condition. The proportional response rate change from one condition to the next provides a measure of resistance to change. The greater the resistance to change, the stronger is the behavior. In terms of Behavioral Momentum Theory, the maintaining reinforcement conditions establish behavioral mass. The greater the mass of behavior, the greater will be its resistance to change when force of a given level is applied.

Both of the approaches to behavioral strength demonstrate that the higher the value of reinforcement, the higher is the strength of behavior maintained by it. The present study asks, 'what is the effect of behavioral mass on the relationships between reinforcers and responses described by the Law of Effect?'

There are a number of procedural similarities between resistance-to-change research and Law of Effect studies. Nevin has varied reinforcer rate in a temporally distant component to bring about contrast effects in two target components where different reinforcer rates establish behavioral masses. The methodology of these studies is very similar to that of the Law of Effect studies. For example, Spealman and Gollub (1974) found that when the reinforcer rate

in one component was altered, response rates in the alternative component changed less the more highly they were reinforced. That is, more frequently reinforced components displayed less contrast. Likewise, Nevin (1974, Experiments 1 and 2) found that when response-independent food was delivered in a third component contrast effects could be observed in the other components. Nevin noted that behavior in the component supporting the highest reinforcer frequency changed less from its baseline level (i.e. showed lower contrast).

Another procedural similarity between resistance-to-change research and Law of Effect studies has been the manipulation of the maintaining reinforcer rate to alter responding. Altering the maintaining reinforcer frequency has been the major manipulation used in Law of Effect studies to examine the hyperbolic relationship and matching relationship discussed in Sections 1.2.1 and 1.2.3 respectively. Nevin, also, has varied the reinforcer rate as a means to exert force. To manipulate reinforcer rate, Nevin has changed the reinforcer rate to extinction in two components that differ only by their maintaining schedule of reinforcement (e.g. Nevin, 1974 Experiment 2; and Nevin, 1988). Given the similarities in the procedures used to investigate resistance to change and behavioral phenomena examined in the Law of Effect tradition it would be surprising if Momentum Theory did not have some implications for the Law of Effect.

There are some methodological differences, however, between the two areas of research. Law of Effect studies run a reinforcer condition for a number of sessions until behavior

has stabilised. In this way the behavioral phenomena are said to be present in steady-state responding.

Resistance-to-change research has typically allowed behavior to stabilise (and gain mass) in a baseline condition. However, subsequent force is only applied for a few (or one) sessions. If the effects of differential mass on steady-state behavioral phenomena are to be assessed then these effects must be shown to be persistant throughout many sessions of training.

There are methodological problems in extending resistance to change assessment techniques into the behavioral phenomena investigated by Law of Effect studies. As noted above, varying dark-key food is very similar to Law of Effect studies investigating contrast arising from reinforcer rate alterations in a temporally distant component. But the Law of Effect also specifies another type of reinforcer rate manipulation - alterations in the maintaining reinforcement schedule. Extinction is the procedure used by resistance-to-change investigators to assess resistance to change following alterations in the maintaining reinforcer rate (e.g. Nevin, 1974 Experiment 2). However, attempts to assess resistance to change using this manipulation are not methodologically sound.

Extinction as an assessment procedure confounds differences in resistance to change. Research examing resistance to change assumes that the force is exerted equally over the two target components. Prefeeding and response-independent food are useful because their effects are evenly distributed between components. However, the use of

extinction violates this assumption. The behavior maintained by the higher rate of reinforcers (the high mass behavior) has more force applied to it than the lower mass behavior. Changing a high reinforcer rate to extinction is a greater change in the reinforcer conditions than changing a low reinforcer rate. The disrupting force is being applied unevenly across components. Furthermore, because two behaviors with differential masses are being compared a constant mass ratio is necessary over the course of disruption. Baseline schedules of reinforcement create a mass difference between the components. Extinction removes the baseline schedules of reinforcement, and therefore, the greater the number of sessions spent in extinction the less the differences in mass are. Examining steady-state behavioral phenomena using extinction as means to alter the maintaining reinforcer rate, and thereby apply force, is methodologically unsound.

The role of reinforcer rate change in altering steady-state responding, as a function of mass, remains an open question. This issue needs to be addressed if the implications of Momentum Theory for the Law of Effect are to be clarified. The present experiments will do this.

1.4.2 The Present Experiments

Experiment one

To examine reinforcer rate change acting as a force, mass must be established by some other aspect of the reinforcement

situation that can remain constant. Experiment one examined whether reinforcer duration acts as a contributer to behavioral mass in steady-state responding. Nevin (1974, Experiment 3) investigated the effect of reinforcer duration on resistance to change. He found that in two components of a 3-ply multiple schedule the rate of responding decreased when response independent food was available during the third, dark-key component. Responding in a component maintained by a longer reinforcer duration decreased less (as a proportion of baseline) than behavior maintained by a shorter reinforcer duration.

Nevin's (1974, Experiment 3) does not provide strong evidence that reinforcer duration can be used as a means to establish mass when examining reinforcer rate change as a force. Law of effect studies have generally maintained a set of reinforcer conditions over a number of sessions. After extended exposure behavior adjusts to the reinforcement conditions and ceases to vary in any great way from session to session. In this way researchers can be sure that they are examining behavioral phenomena that are present in steady-state responding rather than transient changes. Nevin only examined the influence of a force applied for one session. There is a possibility that the mass established by reinforcer duration has only a temporary influence on resistance to change. For a larger reinforcer, a decrease in behavior may not be as rapid when a force is applied. Given extended exposure over a number of sessions the response rate in the long reinforcer component may eventually change just as much as behavior in the short reinforcer component.

Experiment one ascertained whether behavior supported by a high duration of reinforcement changes less (as a proportion of baseline) than behavior reinforced at a lower duration, and whether this difference persists over a number of sessions.

The present procedure is very similar to Law of Effect studies that have examined contrast in multiple schedules (e.g. Reynolds, 1961b and 1963). The major difference is that a mass differential was created across the components. If the contrast effects observed are consistent with Behavioral Momentum Theory then the way is paved to examine other steady-state behavioral phenomena in terms of Behavioral Momentum Theory.

Experiment two

The force applied in Experiment one is response-independent food in a temporally distant component. Experiment two establishes whether changes in the maintaining schedule of reinforcement within a component has differential effects on responding dependent upon behavioral mass.

There is a possibility that reinforcer rate change as a force does not have a greater effect on low mass behavior. Perhaps the latency for the force to take effect is different for different masses. Given enough time, high or low mass behavior may be equally affected by a change in reinforcer rate. Research has not determined whether reinforcer-rate change acts as a force with transient effects or with effects relevant to steady-state responding.

Experiment two ascertains whether reinforcer rate change in a component causes greater proportional change in low mass

responding than in high mass responding, and whether this difference persists over a number of sessions. A mass differential is established by presenting reinforcers of different durations in the two components. Over conditions, the rate of reinforcement is varied equally in the two components. This procedure is more desirable than using extinction because the differences in mass (established by reinforcer duration) are maintained throughout the application of force and do not diminish over time. Therefore, any differences in resistance to change observed between one component and the other are due solely to the differences in mass.

The methodology of the present experiment is very similar to studies which have examined absolute response rates versus absolute reinforcer rates (e.g. McDowell and Woods, 1984). By maintaining the mass differential over the changes in reinforcer rate the hyperbolic relationship for different masses can be compared. However, no studies to date have established a difference in mass over two components in a multiple schedule and then subsequently manipulated reinforcer rate.

Experiment three

Given that mass established by reinforcer duration and force applied by reinforcer rate change have consistent effects in steady-state responding, we have the tools to re-examine matching behavior. Experiment three examines the effect of behavioral mass on the generalised matching relationship.

In a two-component multiple schedule, if behavior in both components possess high mass (e.g. long reinforcers supporting behavior) then the response rate in each component will change less than if both possessed low mass. Consequently, it is expected that the ratio of behavior in Component one to Component two (B1/B2) will change less when behavioral mass is high. The more B1/B2 varies, the more it will come to match (equal) the ratio R1/R2. That is, low mass responding should show greater sensitivity to the reinforcer ratio.

To examine sensitivity when a differential in the mass-establishing conditions is present, two series of conditions are used. One series generates a matching line by altering the reinforcer-rate ratio with a short reinforcer duration. The other series generates a matching line via the same alterations in the reinforcer-rate ratio, but at a long reinforcer duration is used.

Studies which have varied the ratios of component reinforcer rates in a multiple schedule have not compared a series of conditions under one common reinforcer duration against the same series of conditions with a different common reinforcer duration (e.g. Reynolds, 1963; Charman & Davison, 1983; and McLean, 1988). Consequently, the effect of reinforcer duration on sensitivity to reinforcer ratios in multiple schedules is not known.

EXPERIMENT ONE

2.1 INTRODUCTION

Nevin (1974, Experiment 3) investigated reinforcer duration as a contributor to the resistance to change displayed by responding. Two pigeons were exposed to a multiple VI 1-min VI 1-min schedule with 7.5 and 2.5 seconds of reinforcer delivery per reinforcer respectively. Between each component was 30 seconds of 'dark-key'; (i.e. all stimuli were off and reinforcers were not available). Nevin used the dark-key period to exert a force across both components that would change response rates in the target components but maintain baseline reinforcement conditions. He found that in a single session of response-independent reinforcement in the dark-key, the rate of responding in both components decreased. However, behavior in the component correlated with the longer duration reinforcers changed less as a proportion of baseline than behavior reinforced with the shorter duration. The finding was interpreted by Nevin (Nevin, 1974; 1979) as demonstrating that longer durations of reinforcement were similar to higher frequencies of reinforcement in that they established greater resistance to change. In terms of Behavioral Momentum Theory, Nevin's results indicated that the longer the reinforcer duration, the greater is the behavioral mass that is established.

However, it is not clear from Nevin's study that reinforcer duration does, in fact, act as a contributor to resistance to change. Nevin's study did not differentiate

between two possibilities:

1. The differential effect observed between behavior in the two components is not persistant over time. The difference observed is a difference in time taken to change in accordance with a change in the reinforcer conditions. For the longer reinforcer, a decrease in behavior is not as rapid when response-independent food is introduced. Given extended exposure over a number of sessions the response rate in the long-reinforcer component may eventually change just as much as behavior in the short-reinforcer component.

or, 2. The differential effects observed will be maintained over a number of sessions. Following a rapid decrease in behavior, (but to different degrees), the behavior in each component will stabilise, (i.e. not show any trend in session to session fluctuation of response rate). Furthermore, behavior in each component will stabilise at different levels relative to their pre-established baselines. If the predictions from Behavioral Momentum Theory apply to steady-state behavior, then it would be expected that the proportion of change for response rates in the long-reinforcer duration component would be less than that in the short-reinforcer duration component even after behavior reaches stability in both components. In this case the difference between the two responses is not one of latency to change but overall magnitude of change.

There is reason to believe that the second possibility outlined above is more likely. Reynolds (1963) found that greater contrast was obtained when the constant component was held at VI 180-sec rather than VI 95-sec. In terms of

Momentum Theory, responding in the VI 180-sec condition possessed lower mass than responding in the VI 95-sec condition. Therefore, the low mass behavior in the VI 180-sec condition was more influenced by temporally distant reinforcement. Reynold's study showed that when conditions are run over a number of sessions the greater resistance to change of frequently reinforced behavior persists if the reinforcement conditions that cause the effect persist over time.

Nevin (1988) reported an experiment that demonstrated that the difference in resistance to change between intermittent and continuous reinforcement (CRF) was greater after extended training. A different reinforcer rate was arranged for both components. Following fifty reinforcer deliveries in a component a set period of signalled extinction occurred in that component.

Nevin broke up the 64 minute period of extinction into 4, 16 minute quarters for the purpose of analysis. The first quarter was used as an arbitary baseline to calculate proportion of change. It was shown that in Sessions 2-5 there was little difference between CRF and VI 30-sec in terms of resistance to change. However, by Sessions 75-125 CRF responding was more persistant during periods of extinction than intermittently reinforced behavior was. Hence, it was demonstrated that after many sessions of force application differences in resistance to change established by reinforcer rate were present.

Despite the indicators, there remains doubt that different reinforcer durations will act as a means to

establish differences in resistance to change over a number of sessions. While Nevin (1974 Experiment 3) did show greater resistance to change for responding maintained by shorter reinforcer durations, when extending the results to steady-state performance the conclusions are open to interpretation. Furthermore, Nevin used two birds and only obtained a clear effect for one of them. Also, the findings of differences in resistance to change persisting over a number of sessions have only been demonstrated for mass differences established by reinforcer rate.

The present experiment investigated whether behavioral mass established by reinforcer duration has an effect on resistance to change that persists over time, and uses dark-key response-independent food as a force to disrupt the reinforcement conditions.

Experiment one is an investigation which takes aspects of two previously separate lines of research and combines them to pave the way for further investigation. Experiment one examines whether the two approaches outlined earlier (in Section 2) for examining response strength can address the same types of data. The existance of nontransitory relationships between reinforcers and responding can only be demonstrated if responding is allowed to reach stability. Therefore, it is necessary to extend the resistance to change research paradigm to steady-state performance under intervention, rather than the alternative of examing the effect of a *single* session of intervention on long term behavior. The measure of interest remained a comparison of the proportional response rate change between components of a

multiple schedule where the mass of the behavior in each component is different from the other. Given that the force was applied across a number of sessions, the reinforcer conditions that create a differential in mass in the two components had to be maintained throughout. In the present experiment, responding in one component was always maintained by 6 seconds of reinforcement and that in the other with 2 seconds of reinforcement.

2.2 METHOD

2.2.1 Subjects

Four locally obtained homing pigeons with a history of training in multiple schedules were maintained at 80-85% of their free-feeding weights by supplementary feeding. Water and grit were continuously available in the home cages.

2.2.2 Apparatus

Four light-proof sound-attenuating pigeon chambers, 32 cm high, 34 cm deep, and 34 cm wide were each fitted with 3 response keys (21 cm from the floor), a house light, and a hopper containing wheat (6 cm from the floor and directly below the center response key). The house light and the two side response keys were never used. The center response key was illuminated either red (S1) or green (S2), or was off entirely (dark key phase). Pecks exceeding .15N produced .05

seconds of keylight offset. During reinforcement the keylight was turned off and the hopper was illuminated in white light. Extraneous sounds were masked by a ventilation fan in each chamber. All experimental events were controlled and recorded by an I.B.M compatible computer running MED-PC Version 4 software.

2.2.3 Procedure

The center key was illuminated red or green for one-minute periods in irregular order. Responses on the center key were reinforced according to Fleshler-Hoffman (1962) VI schedules. The arranged schedule of reinforcement was VI 120-sec for each component, and this was maintained throughout the experiment. When a reinforcer was delivered during S1, wheat grain was presented for 2 seconds. When a reinforcer was delivered during S2, the duration of access to grain was 6 seconds. The stimuli (red in S1 and green in S2) were turned off for the duration of reinforcment presentation. The one-minute component timer also stopped during reinforcement.

Each session began with a 30 second period with the center key dark, and 30 second dark key periods always intervened between components. Sessions consisted of 12 presentations of S1 and 12 presentations of S2. In successive conditions of the experiment response independent food was presented at different rates during the dark-key periods between components. The series of conditions each pigeon was

exposed to is shown in Table 2.1.

Table 2.1

Schedule combinations in each condition (in seconds), order of exposure for each bird, and number of sessions to reach stability (in parentheses) in Experiment one.

Schedule Combinations

Condition	*S1 (red) (2-sec.renf)*	*S2 (green) (6-sec.renf)*	*dark-key schedule (3-sec.renf)*
1	VI 120	VI 120	0
2	VI 120	VI 120	VT 120
3	VI 120	VI 120	0
4	VI 120	VI 120	VT 30

Order of Condition Exposure and Sessions to Stability

Pigeon				
C5	1(21)	2(22)	3(18)	4(30)*
C6	1(20)	2(23)	3(18)	4(23)
C7	1(21)	4(26)	3(17)	2(15)
C8	1(20)	4(26)	3(15)	2(17)

* condition terminated before stability criterion reached.

All pigeons began in Condition one where no response-independent food was presented during dark-key periods. In Conditions 2 and 4 response-independent food was presented on VT 120-sec and VT 30-sec schedules respectively in the dark-key periods. Condition three was a return to baseline reinforcement conditions (i.e. no response-independent food was available during the dark key periods). The return to baseline was necessary to ensure that the baseline levels of responding had not shifted since the start of the experiment. By having a baseline immediately preceding the introduction of response-independent food a more

accurate measure of proportional response rate change was possible for each experimental condition. The duration of access to response-independent food was always 3 seconds.

The procedure was run seven days a week at approximately the same time every day. For each bird daily sessions were continued within a condition for at least 15 sessions (20 for Condition one) and until a stability criterion had been met. A criterion value was calculated by taking 5 successive averages of absolute response rate in a session for a single component. Each average was calculated from the mean response rate for 5 successive sessions. For example, after 15 sessions in a condition, absolute response rates in sessions 7,8,9,10, and 11 were averaged to give the first average, sessions 8,9,10,11, and 12 were averaged to give the second average, and so on until 5 such averages were obtained. The mean was then obtained of the five averages in a single component in order to gain a single average for absolute response rates over the past 9 sessions. The criterion was that each average in a component was not different by +/- 7.5% from the overall average in that component from the last 9 sessions. The criterion requirement had to be met in each component simultaneously before the subject could proceed to the next condition. Bird C5 had failed to meet the criterion for the final condition. Therefore, after 30 sessions, C5 was withdrawn from Condition 4. (See Appendix A for the BASIC program that calculated the stability criterion. Also, see Appendix B for a plot of the raw data from the present experiment and the points at which stability was reached).

2.3 RESULTS

The summary data used for analysis in the present experiment were means from the five sessions at the start of an experimental condition and means from the last five sessions of a condition when behavior was stable according to the criterion. The last five days in a baseline condition were used to calculate steady-state baseline performance.

Appendix C gives each bird's mean response rate, proportion of baseline response rate, and reinforcer rate in each component for each condition. Response and reinforcer rates are measured in terms of number of responses or reinforcers per hour in each component. Two measures have been used by Nevin and colleagues to measure change from baseline responding (e.g. Nevin, 1974; Nevin, Mandell and Atak, 1983; and Nevin 1988). A measure of response rate change can be gained from (Bo - B*x*) / Bo, where Bo is the baseline response rate and B*x* is the response rate once the force, of value *x*, has been applied. Another measure of change is gained by dividing Bo by B*x*. Irrespective of the measure used, the greater the resistance to change (and therefore, behavioral mass), the closer it is to a value of 1.0. The measure of change chosen for use here is Bo/B*x*.

Figure 2.1 shows proportion of baseline response rate plotted as a function of the response-independent reinforcer rate. For each bird two graphs are given. The graph on the left shows the proportional response rate change in each component from the initial five sessions in each of the two experimental conditions (VT 30-sec and VT 120-sec). These

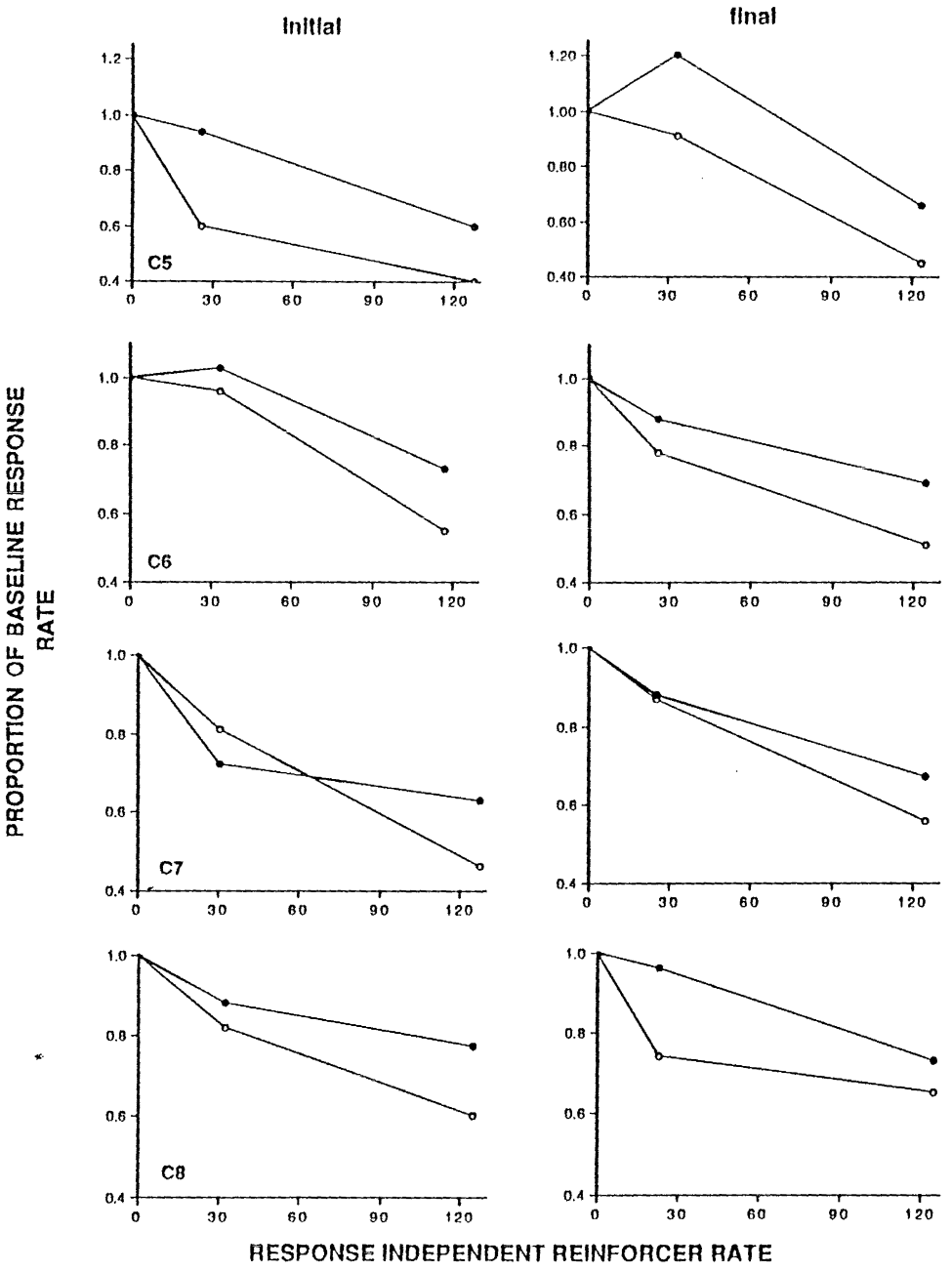

FIGURE 2.1 Proportional change in response rates as a function of rate of the obtained response-independent food delivery. Filled circles represent behavior maintained by 6 second duration reinforcers. Unfilled circles represent behavior maintained by 2 second duration reinforcers. The left hand graphs show proportions of change in the initial five sessions of a response-independent food condition. The right hand graphs show data from the final five sessions of a condition.

graphs are comparable to those obtained by Nevin (1974, Experiment 3). Nevin calculated response change after just one session of intervention, and therefore, was also examining the initial effects of force on behavior.

The right hand graphs in Figure 2.1 show the proportion of baseline response rate in each component from the last five sessions in a condition. These graphs are comparable to those obtained by researchers investigating contrast (e.g. Reynolds, 1963). Contrast is obtained after a condition has been in place for typically more than 15 sessions. The graphs on the right hand and contrast studies are both investigations of nontransitory, steady-state behavior.

For the 'initial' and 'final' graphs, baseline response rate (Bo) was obtained by averaging the response rate from the last five sessions of preceding baseline. Initial response rates in the new condition (Bxi) were obtained by averging the response rate in the first five sessions of a condition, for each component. The final response rate was obtained by averaging the response rate in the final five sessions of a condition for each component. The average response rate was an accurate measure of steady-state responding since the criterion specified a maximum allowable variability over sessions.

The presentation of response-independent food in the dark-key component caused a decrease in responding in the other two components. The greater force of VT 30-sec had the effect of decreasing response rates to a greater degree than VT 120-sec in both components. All birds displayed a greater reduction in response rate (relative to baseline) in the

component which arranged short-duration reinforcers (S1) than in the component with long-duration reinforcers (S2) for the initial sessions of response-independent food delivery; (except for C7 when response-independent food was delivered on the VT 30-sec schedule). These results are similar in nature to those of Nevin (1974, Experiment 3). Nevin demonstrated that the greater the rate of response-independent food applied, the greater the suppression of behavior in both components. Nevin also found a greater proportional behavior change in a component arranging short reinforcers as opposed to long ones.

Figure 2.1 indicates that a very similar pattern of results emerges when the final five sessions in a condition are compared with the initial five. After a minimum of 15 sessions the response rates in the short-reinforcer duration component still display a greater change in proportion of baseline responding than does behavior in the long-reinforcer duration component. As with the initial sessions, VT 30-sec in dark-key periods had a greater influence on behavior in both components than VT 120-sec.

2.4 DISCUSSION

The results showing proportionately greater change in response rate for behavior maintained by short reinforcers within the first few sessions of response-independent food being made available is consistent with the findings of Nevin (1974 Experiment 3). Figure 2.1 showed that the VT 30-sec

schedule presented during the dark-key component had a greater effect in suppressing behavior in both components than VT 120-sec within the first few sessions. This finding is also consistent with Nevin (1974 Experiment 3).

In terms of Behavioral Momentum Theory, the slope of the function when proportion of baseline is plotted against various values of the force applied (response-independent food in the present case) is an indication of mass (Nevin, 1988). The shallower the slope the greater is the behavioral mass. In the present experiment, as in Nevin's (1974 Experiment 3) the slope of the function for S2 (long reinforcers) is shallower than that of S1 (short reinforcers). Hence, behavior in S2 possesses greater resistance to change than behavior in S1 due to the longer reinforcer duration in S2 establishing a higher level of behavioral mass.

The present experiment expanded upon that of Nevin's (1974 Experiment 3). If the conditions which bring about a change in behavior are maintained over a number of sessions, along with a constant mass difference across components, the differential in resistance to change observed at the start is maintained throughout a condition. It was shown here that responding in S1 was still less resistant to change even if the measure of resistance to change (proportion of baseline responding) was obtained after behavior had reached stability. The effect of applying a force to behavior was still present and consistent with the differences in the mass-establishing conditions after an extended number of sessions. Therefore, when reinforcer duration establishes a mass difference and response-independent food is used as a force then Behavioral

Momentum Theory can be extended to include steady-state responding.

The greater the force applied (VT 30-sec as opposed to VT 120-sec) the greater the change in response rates for both components even after a number of sessions of force application. These particular findings show the presence of a contrast effect which is a behavioral phenomenon observed in steady-state multiple-schedule performance. If dark-key phases are treated as a third component, then it can be seen that as more reinforcement is gained in the dark-key, the greater is the contrast (i.e. the decrease in response rates in the other components). In this case the component with the greater mass shows less contrast than the component with lesser mass. Whether proportional change is used a measure or absolute response rates, contrast is greater in low-reinforcer duration components.

Findings of greater contrast with shorter reinforcer durations is consistent with studies showing greater contrast for responding maintained by low-reinforcer rates. Greater contrast at low reinforcer rates has been shown by researchers using two (e.g. Reynolds, 1963), or three (e.g. Nevin and Shettleworth, 1961) components in a multiple schedule. Nevin (1974) concluded that reinforcer duration contributed to resistance to change in much the same way as reinforcer rate did. Behavior reinforced with either a high reinforcer rate or a long reinforcer duration changes less as a proportion of baseline following a force being applied than does behavior maintained by a low-reinforcer rate or short duration.

Herrnstein's (1970) equation predicts contrast effects

when one components reinforcer rate is altered in a multiple-schedule procedure. Herrnstein's equation does not predict the greater contrast effect obtained when responding is being maintained by a low-reinforcer rate or short duration. Behavioral Momentum Theory does account for these findings in terms of the behavioral mass established by reinforcer rate and duration contributing to resistance to change.

The most common manipulation in Law of Effect research is to alter the reinforcer rate to observe the effect on steady-state response rate. The intention of Experiment one was to establish whether differential resistance to change was persistant in steady-state behavior. In order to come one step closer to determining whether Behavioral Momentum Theory can be applied to the same phenomena examined by Law of Effect studies, Experiment two investigates whether a change in the reinforcer rate maintaining responding acts as a force with effects that are dependent upon mass. The limitation of Experiment one is that force was applied extraneously to behavior in the components. Now the question asked is, whether a force applied within the reinforcement conditions of a component (as is done in Nevin's extinction procedure) act in a way consistent with predictions from Behavioral Momentum Theory?

EXPERIMENT TWO

3.1 INTRODUCTION

Experiment one examined reinforcer duration as a determinant of behavioral mass. The second experiment in the present series retained reinforcer duration as the determinant of a mass differential. Whereas Experiment one studied dark-key food rate as the means to apply force to two responses of different mass, the current experiment examined alterations in the maintaining reinforcer rate as a force.

'Force' is an important aspect of Behavioral Momentum Theory. To determine behavioral mass requires some form of change or disruption to the reinforcer conditions. The subsequent resistance to the change shown by responding yields a measure of mass. Nevin (1974) investigated some of the aspects of the reinforcer situation that contribute to resistance to change. Frequency, duration and delay of reinforcement were all found to be important factors. In 1979 Nevin discussed a number of procedures which could be used to assess resistance to change. In terms of Behavioral Momentum Theory, such assessment procedures must apply force to responding. The common methods of exerting force have been to introduce an event into the reinforcer situation (e.g. concurrent punishment), or, to decrease the relative value of scheduled reinforcers (e.g. by presenting response-independent food in another component). However, these are indirect ways to exert force. By and large most studies of steady-state behavior have examined changes in the reinforcer rate of the

maintaining schedule as a means of changing behavior. If our goal is to examine the implications of Behavioral Momentum Theory for steady-state behavioral phenomna then the way in which change in the maintaining reinforcer rate acts as a force must be investigated.

There is no absolute scale by which to measure resistance to change. Consequently, resistance to change for one behavior must be compared against another if one is to assert that a given behavior is strong or weak. Force must be applied evenly to the two performances being compared if any conclusions about behavioral strength are to avoid being confounded by the assessment procedure itself.

The examination of reinforcer rate change as a force in momentum studies has not been properly conducted. The only method used to examine reinforcer rate change in the maintaining schedule as a disruptor to assess resistance to change has been via the extinction procedure (e.g. Nevin, 1974 Experiment one; Nevin et al, 1983). However, Nevin's extinction procedure cannot be used as a force in the Behavioral Momentum paradigm. The use of extinction as a force contravenes the requirement that force be applied evenly to the assessed behaviors. The problem arises because a difference in reinforcer rates across behaviors is the standard way in which to create a mass differential. However, changing both schedules of reinforcement to extinction is a greater change (force) in the conditions for the more frequently reinforced behavior. Furthermore, because the difference in mass may be due only to the frequency of reinforcement, altering both schedules to extinction removes

any mass differential. Therefore, using extinction to examine differences in resistance to change (when reinforcer rate is used to establish mass) confounds the conditions which establish mass and those which exert force.

The difficulty of using extinction was highlighted by Nevin, Mandell and Atak (1983) when they compared extinction and response-independent food procedures. They presented pigeons with three ratios of reinforcement: multVI 129-sec VI 42-sec, VI 42-sec VI 10-sec, and VI 129-sec VI 10-sec. According to Behavioral Momentum Theory, as the scheduled reinforcer ratio increased the observed mass ratio should also increase by the same proportion. A mass ratio can be obtained by taking the proportional change for responding in one component and dividing it by the proportional change in the other. A linear relationship described the function relating increases in the reinforcer ratio and increases in the mass ratio when response-independent food was used as a force. However, mass ratios obtained when extinction was used as a force were invariant with increases in the reinforcer rate ratio.

The purpose of Experiment two was to examine reinforcer rate change as a force in steady-state behavior. The procedure altered the maintaining reinforcer rate in the two components without altering the conditions maintaining a constant mass differential. Experiment one demonstrated that different reinforcer durations could be used to establish and maintain a differential in mass across components. In Experiment two, the maintaining reinforcement schedule arranged a mass differential via unequal reinforcer durations

across components. The maintaining schedule exerted force, also, via alterations in the reinforcer rate. Changing the maintaining reinforcer rate in both schedules by an equal amount applied force equally across components. Unlike using Nevin's extinction procedure the conditions creating a mass differential (reinforcer duration) are not altered by application of the force (reinforcer rate change).

The present procedure is similar to that used by McDowell and Wood (1984) and Bradshaw, Szabadi and Bevin (1978) in single schedules, and Davison (1988) in concurrent schedules. In these studies reinforcer duration was the only difference between a series of schedules (for McDowell & Wood and Bradshaw et al) and concurrent alternatives (for Davison). The present study was a comparison of performance in components of a multiple schedule. Multiple schedules have been the most common method of investigating resistance to change.

A limitation of resistance-to-change research is that the persistance of differences in resistance to change has not been investigated. Experiment one demonstrated that differences in resistance to change persisted if the conditions which established mass were persistant throughout a number of sessions of force application. In Experiment one the effects of force application were present in steady-state behavior. However, the force used was response-independent food. Force in the form of a decrease in reinforcer rate may act as in one of two ways on responding:

1. Force may initially cause a greater change in a low mass behavior than a high mass behavior. But over a number of

sessions of force application the difference in resistance to change may disappear, not because mass no longer has an influence, but because the effect of the force has diminished.

or, 2. Force may cause a relatively permanent change in response rates. As long as force is applied, observed differences in the amount of behavior change will remain. If the predictions from Behavioral Momentum Theory apply to steady-state behavior then it would be expected that a change in responding maintained by long reinforcers would be less than the change in behavior maintained with short reinforcers even after behavior reaches stability.

3.2 METHOD

3.2.1 Subjects and Apparatus

The subjects and apparatus were the same as Experiment one.

3.2.2 Procedure

The center key was illuminated either red (S1) or green (S2) for 90 second periods in alternating order. Responses on the center key were reinforced according to Fleshler-Hoffman (1962) VI schedules. The arranged schedule of reinforcement was always identical for each component and was altered across conditions throughout the course of the experiment. The only

difference in reinforcer conditions between S1 and S2 was the duration of reinforcement. When a reinforcer was delivered in S1, wheat grain was presented for 2 seconds. When a reinforcer was delivered in S2, wheat grain was presented for 6 seconds. The stimuli (red in S1 and green in S2) were turned off for the duration of reinforcer presentation. Sessions consisted of 14 presentations of S1 and 14 presentations of S2.

The scheduled reinforcer rate was altered over conditions. Every second change in the experimental conditions was a return to mult VI 120-sec VI 120-sec. Mult VI 120-sec VI 120-sec served as baseline condition against which responding in other conditions was compared in order to calculate proportion of baseline response rate. The return to baseline conditions was employed to ensure that if the baseline levels shifted during the course of the experiment then the proportion of change measures would still be accurate. The conditions received by each bird are shown in Table 3.1.

The procedure was run seven days a week at approximately the same time every day. For each bird daily sessions were continued within a condition for at least 20 sessions and until a stability criterion had been met. The stability criterion was the same as that employed in Experiment one.

Table 3.1

Schedule combinations in each condition (in seconds), order of exposure to conditions for each bird, and number of sessions to reach stability (in paraentheses) in Experiment Two.

Schedule Combinations

Condition	*S1(2sec.reinf.)*	*S2(6sec.reinf.)*
1	VI 90	VI 90
2	VI 120	VI 120
3	VI 60	VI 60
4	VI 240	VI 240
5	VI 480	VI 480
6	VI 40	VI 40

Order of Conditon Exposure and Sessions to Criterion

Pigeon							
C5	2(23)	3(20)	2(20)	4(20)	2(20)	5(20)	
C6	1(20)	2(21)	5(22)	2(20)	3(20)	2(20)	6(20)
C7	2(24)	4(24)	2(20)	5(20)	2(20)	3(21)	
C8	1(20)	2(20)	4(20)	2(20)	3(20)	2(20)	5(21)

3.3 RESULTS

The summary response rate data used for analysis in the present experiment were the means from the last five sessions of a condition when behavior was stable according to the criterion. Reinforcer rate means were taken from the last ten sessions of a condition because, particularly at low reinforcer frequencies, there was a large variation in the obtained reinforcer rate. Appendix E gives each birds' mean response and reinforcer rates in each component for every condition. Rates were calculated by taking the absolute number of response or reinforcers in a component and dividing by the time spent responding in that component. The time

spent responding in a component was component duration (90 seconds) minus the time for which reinforcers were made available. These measures represent the responses emitted in a component relative to the time available for responding.

Two measures of response strength were obtained in Experiment two; absolute response rate and proportional change in response rate from a baseline level. For calculating the mean absolute response rate in the VI 120-sec VI 120-sec condition, the average of all repeats of this condition were used. For calculating change in the response rate, the VI 120-sec VI 120-sec condition immediately preceding each reinforcer rate change was used as the baseline condition. (See Appendix F for the response and reinforcer rates obtained from each baseline condition). For Birds C6 and C8 there was no baseline condition preceding Condition one. The baseline condition that followed Condition one was therefore used to provide an estimate of baseline response rate for Condition one.

Absolute Response Rate

Figure 3.1 shows the change in absolute response rates as a function of absolute reinforcer rates for S1 and S2. Data are presented separately for each bird, as well as for the group as a whole. Group analyses, here and elsewhere, show only conditions to which all four birds were exposed. For all birds and the group, as the absolute reinforcer rate increased so did the absolute response rates. In most cases the function relating absolute reinforcer and response rates was well fitted by the hyperbolic function given by Equation 6.

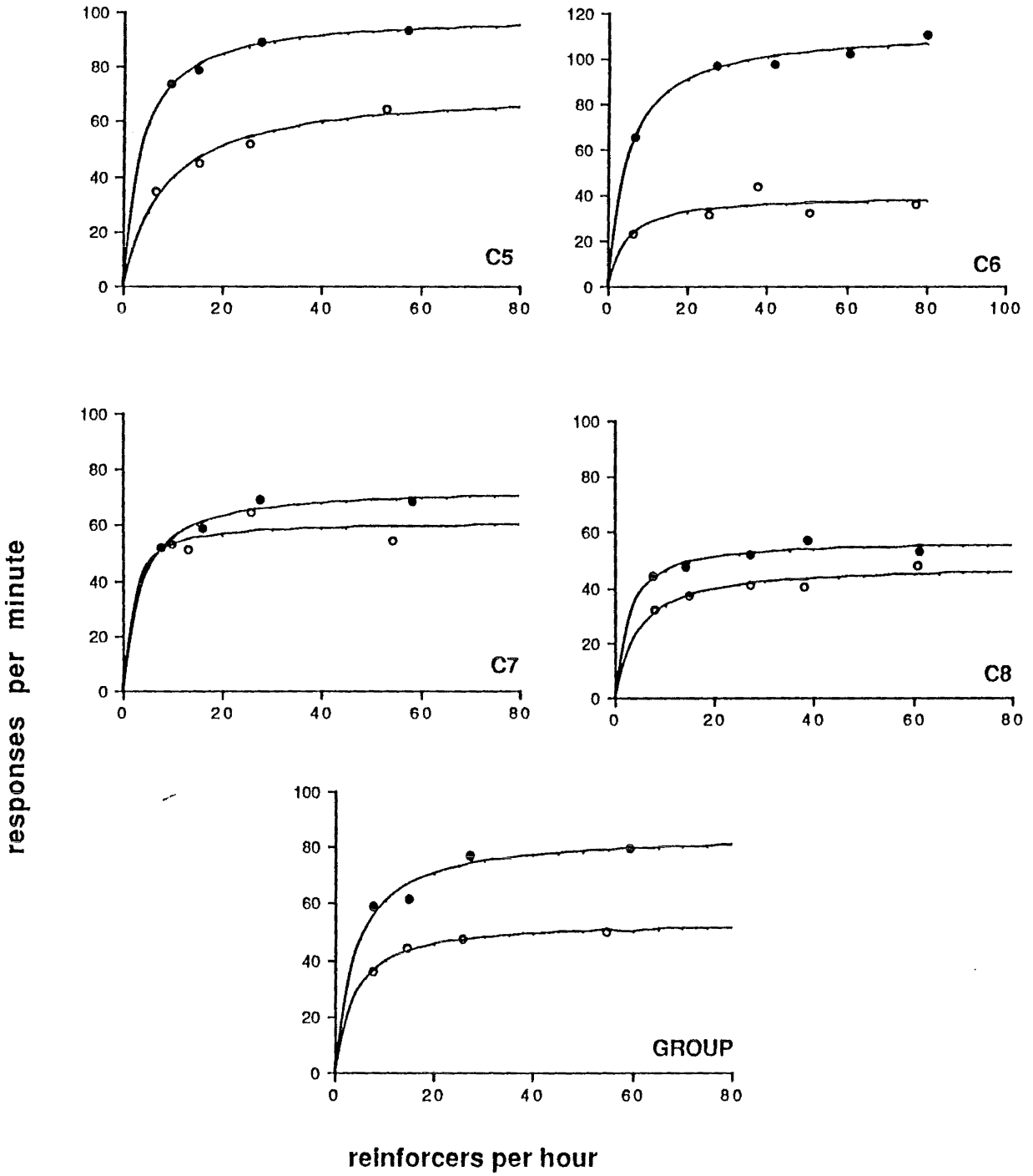

FIGURE 3.1 Absolute response rates (responses per minute) in S1 and S2 plotted as a function of obtained absolute reinforcer rates (reinforcers per hour). Closed circles are response rates in S2; 6-second reinforcer duration. Open circles are response rates in S1; 2-second reinforcer duration

Fitting Equation 6 to the data in Figure 3.1 yields estimates of two free parameters; *k* and Ro. *k* provides a measure of asymptotic responding. Ro was interpreted by Herrnstein (1970) as a measure of the extraneous reinforcer rate measured in the same units as the arranged food reinforcers. The obtained values of *k* and Ro, and the mean squared errors for the fits are given in Table 3.2.

Table 3.2

Values of k and Ro obtained from fitting Equation 6

Pigeon	*Component*	*k*	*Ro*	*mean sq.error*
C5	S1	72.17	8.29	5.54
	S2	99.37	3.41	1.05
C6	S1	39.76	4.38	18.07
	S2	113.15	4.91	7.82
C7	S1	61.23	1.50	29.76
	S2	73.55	3.25	4.37
C8	S1	48.17	4.37	4.03
	S2	56.94	2.29	3.30
GROUP	S1	53.75	3.59	0.74
	S2	84.56	3.89	10.31

Hyperbolas were fitted using the Wetherington and Lucas procedure (Wetherington and Lucas, 1980). The mean squared error (MSE) measures in Table 3.2 provide a measure of how well the predicted hyperbola fits the obtained data. Low values of MSE indicate good fit. Within subjects, hyperbolas fitted better at the 6-second reinforcer duration than at the lower 2-second reinforcer duration.

Response rates were always greater in S2 (6-second reinforcer duration) than in S1 (2-second reinforcer duration). A comparison of the fitted hyperbolas indicated

that the measures of *k* were greater in S2 than in S1. The higher level of asymptotic responding at 6-second reinforcers as opposed to 2-second reinforcers is comparable to the results of McDowell and Wood (1984) and Bradshaw et al (1978). These researchers found that with increasing reinforcer magnitude, the value of *k* increased.

Resistance to Change

Change in response rate from a baseline level was measured using the ratio Bx/Bo described in Experiment one. For each bird, response rates at each reinforcer rate (level of force) were divided by the response rate in the immediately-preceding VI 120-sec VI 120-sec condition, (except for the two instances noted above). Measures of response rate change were calculated separately for S1 and S2. Response rates were the mean of the last five sessions in a condition. Reinforcer rates were the mean from the last ten sessions of a condition.

Figure 3.2 shows the proportional change in response rates as a function of the change in absolute reinforcer rate. Data are presented separately for each bird as well as for the group as a whole. For the group, as absolute reinforcer rate increased the proportional change in responding increased. For reinforcer rates below baseline level (VI 120-sec), the proportional change in responding was below 1.0 (i.e. decreased). For those reinforcer rates above baseline, proportional change in responding was above 1.0 (i.e. increased).

If responding in S1 was less resistant to change than

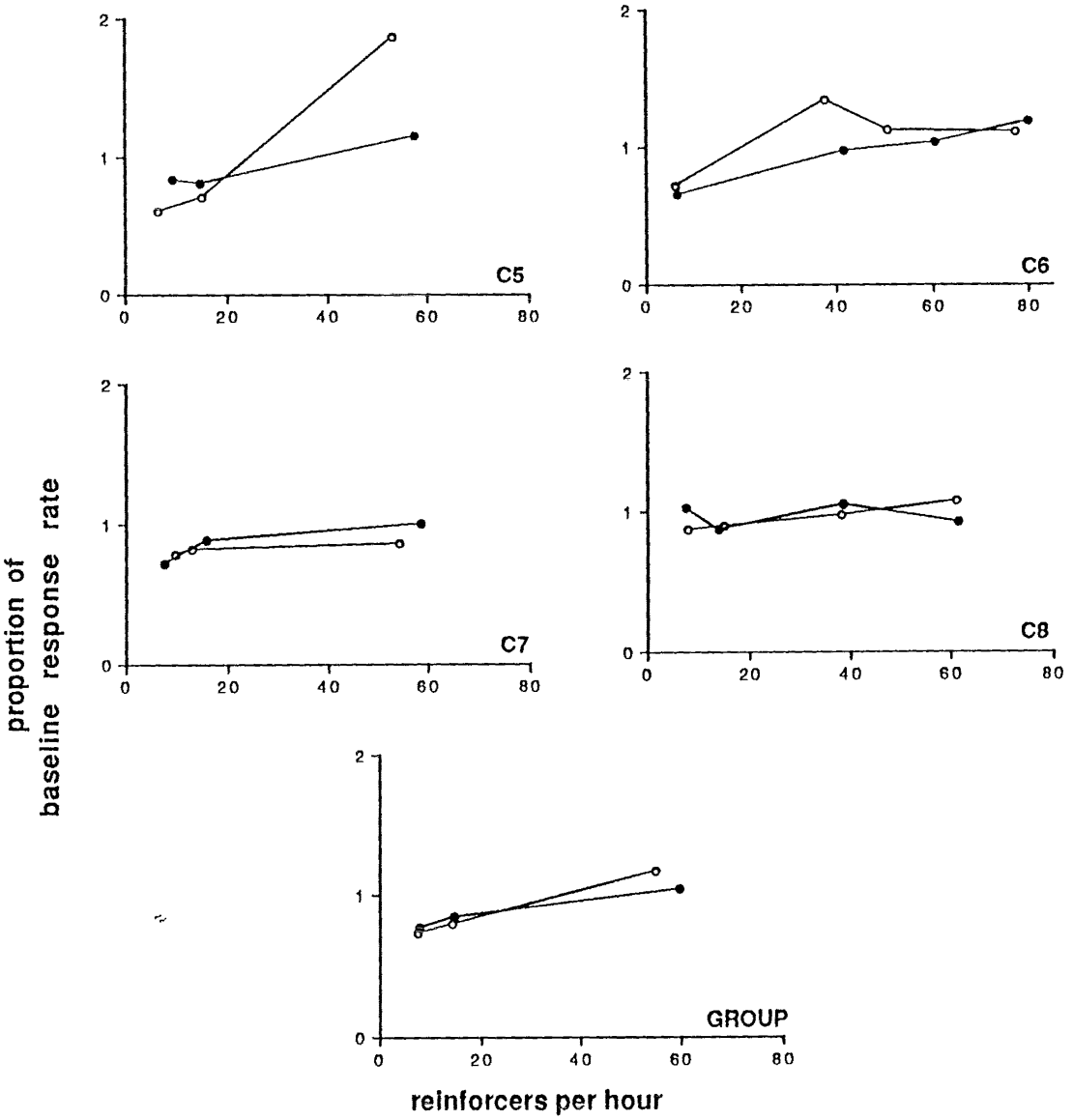

FIGURE 3.2 Proportion of baseline response rate in S1 and S2 plotted as a function of the obtained absolute reinforcer rate (reinforcers per hour). Proportion of change measures are the rate of responding at a given reinforcer rate divided by the response rate in the immediately preceding baseline condition. Closed circles are proportions of change in S2 (6 second reinforcer duration). Open circles are proportions of change in S1 (2 second reinforcer duration).

responding in S2, then the functions relating absolute reinforcer rate to proportional change would have been steeper for S1 than S2. The two slopes would be expected to intersect since at reinforcer rates higher than baseline, responding in S1 would have shown proportions of change further above a value of 1.0 than S2. At reinforcer rates lower than baseline, responding in S1 would have shown proportions of change further below the value of 1.0 than S2. However, for most subjects there was little systematic change in response rate (relative to baseline rates) from condition to condition. Only one of the four subjects, bird C5, showed greater proportional change in S1 responding (short reinforcers) than in S2 responding (long reinforcers).

Figure 3.2 was produced by using measures of response rate change obtained from the actual response rates that were observed. However, it is possible that this analysis is overly influenced by random variation in response rates at the extreme reinforcer rates. Change in response rates can also be examined by using data generated from the hyperbolas fitted to the absolute reinforcer and response rates. Using the response rates predicted from the functions enables estimation of response rate change that is uninfluenced by the random variation that is present when using individual data points. To calculate proportional change, the response rate predicted from the function at 80 reinforcers per hour was divided by the response rate predicted at 5 reinforcers per hour. The two points were arbitarily chosen from the two extremes of the function. Using the extremes of the function should maximise the chance of observing differences in proportion of change

between 2- and 6-seconds of reinforcer duration.

Table 3.3 shows the change in response rates predicted at 80 reinforcers per hour as a proportion of response rates predicted at 5 reinforcers per hour. Birds C5, C8 and the group as a whole showed greater change in S1 than S2. Whereas, birds C6 and C7 showed greater change in S2 than S1. Consequently, there is no systematic difference between response rate change at 2- and 6-seconds of reinforcer duration, as reinforcer frequency is altered. These results are consistent with those obtained from the actual response rate changes in Figure 3.2. It is clear that the analysis of response rate change in Figure 3.2 was not overly influenced by random variations in the response rates gained at each reinforcer rate.

Table 3.3

Proportion of change in response rates predicted from the fitted hyperbolic functions.

Pigeon	*S1*	*S2*
C5	2.41	1.61
C6	1.78	1.87
C7	1.28	1.59
C8	1.78	1.42
GROUP	1.64	1.28

Response rate changes were also obtained for the mean of the initial five sessions in each condition. (See Appendix G for the proportional change data obtained in the initial and final five sessions of each condition). These data are comparable with Nevin's in that Nevin has calculated resistance to change after only five or six sessions of

extinction. Nevin, therefore, was also examining the initial effects of reinforcer rate change on proportional response change. In the present experiment initial proportions of change were similar to those found in steady-state responding. Proportional change did not vary systematically between S1 and S2.

To summarise, absolute response rate change with changes in the reinforcer rate were well described by a hyperbolic function. However, as reinforcer rate was altered across conditions, resistance to change did not vary systematically across the two reinforcer durations. This was the case in the initial and final 5 sessions of conditions.

3.4 DISCUSSION

Experiment two investigated the role of reinforcer rate change as a force in Behavioral Momentum Theory. Changes in the reinforcer rate were the same for each component. Each component differed from the other only by the duration of reinforcer delivery. From Momentum Theory it was expected that the mass differential created by unequal reinforcer durations would lead to a difference in the amount of behavior change shown. Specifically, the longer the duration of reinforcement in a component, the less behavior should change with changes in the reinforcer rate.

A comparison of proportional response change revealed that in neither the initial or final five sessions of a condition was there systematically a greater change in

responding at 2- or 6-seconds of reinforcer duration. This result is inconsistent with predictions derived from Behavioral Momentum Theory. A plot of proportional response rate change should result in a 'flatter' function for a behavior if it changes less from one reinforcer rate to the next. A lack of systematic difference between the functions obtained in different components indicated that although overall response rates may have been different, behavior in one component did not change more than behavior in another. The lack of a difference in response change in the initial sessions is in contrast to results obtained when using response-independent food as a force. Experiment one demonstrated that differences in response change besides being present in stable behavior were present at the beginning of force application.

It is worth noting that if extinction had been used as one of the schedule values in the present experiment, the results would almost certainly have shown a higher proportion of change at long reinforcer durations. The response rates after 20 sessions of extinction would be zero in each component. At all reinforcer rates, response rates were greater for long duration reinforcers. The change in responding from zero reinforcers to any other value would have resulted in a greater change for behavior under long duration reinforcers. This finding would have been trivial. As noted earlier (in Section 3.1) extinction removes the conditions maintaining mass. Therfore, using extinction data would have resulted in a comparison of zero mass responding against responding with a constant mass differential across

components.

A possible reason for the lack of difference between long and short reinforcer responding is that not enough force was applied. Perhaps changes in the maintaining schedule of reinforcement were not great enough to cause an obvious change irrespective of mass. This is unlikely because the hyperbolic relationship between absolute response and reinforcer rates indicates that response rates did change with reinforcer rate changes. For both short- and long-duration responding an asymptotic level was reached by all subjects, indicating that any greater changes in reinforcer rate would have had very little effect on response rates.

Perhaps there was not a large enough mass differential in the mass establishing conditions to result in a difference in resistance to change. However, Experiment one established that 2- and 6-second reinforcer durations were sufficient to produce differences in resistance to change when response-independent food was used as a force. It appears that reinforcer rate change in the maintaining schedule is sufficient to change response rates and that the current reinforcer durations are sufficient to create a difference in resistance to change. However, when these conditions are present in the same schedule, there emerges no difference in resistance to change.

The results indicated that response rates in both components were, for most subjects, well related to reinforcer rates by the hyperbolic function found in other studies (e.g. Catania & Reynolds, 1968; McDowell & Wood, 1983; and Bradshaw et al, 1978). A plot of the absolute changes in response

rates (Figure 3.1) revealed that the asymptotic level of responding was always greater at 6 seconds of reinforcer duration. This finding complements that of McDowell and Wood (1984) and Bradshaw et al (1978) who found that as reinforcer magnitude increased (in cents or sucrose concentration, respectively) so did asymptotic responding in single schedules. The results that have indicated a variable k with changes in the reinforcer parameters are unpredicted by Herrnstein's model of absolute responding (Equation 6). Altering the reinforcer duration according to Herrnstein (1974) should have no influence on the relationship observed between response and reinforcer rates.

The present experiment indicated that the hyperbolic relationship tended to fit better at lower durations or magnitudes of reinforcement (low mass conditions). Linear Systems Theory and Equation 6 do not deal with this result. Behavioral Momentum Theory provides a possible explanation. Although reinforcer rate change is the force being manipulated, other extraneous forces are inevitably present and may vary in an uncontrolled manner throughout the experiment. According to Behavioral Momentum Theory, the behavior in Component one should be more susceptible to these extraneous forces, and would be expected to vary with reinforcer rate changes in a less systematic way than behavior in Component two.

McDowell and Wood (1984), Bradshaw et al (1978) and Davison (1988) have performed studies in single and concurrent procedures that can be reanalysed in terms of resistance to change. All studies examined the effect of reinforcer

magnitude or duration on the relationship between response rate and reinforcer rate change.

McDowell and Wood (1984) examined the effect of different reinforcer durations on *k* in Equation 6. McDowell and Wood presented human subjects with a range of single VI schedules over which the reinforcer rate varied. The reinforcer magnitude was varied over sessions from .25^{c} to 35^{c} per reinforcer delivered. Reinforcer magnitude is analogous to reinforcer duration in that it should establish differences in behavioral mass. For the present situation, it is of interest to determine whether response rates changed less as a proportion of baseline with increasing magnitude.

A condition can be chosen arbitarily to represent a baseline. Figure 3.3 shows the grouped data for three of McDowell and Wood's subjects, (see Appendix H for the individual data reanalysed). The proportional change in behavior at each reinforcer rate was gained by taking the response rate in that condition and dividing by the response rate in the lowest reinforcer rate condition (VI 720-sec). Response rates were gained from the average of the first eight stable sessions in a condition. The reanalysis of McDowell and Wood's data indicated the response rates at .25^{c} magnitude (open circles) changed more than response rates at 1^{c} and 35^{c} (closed circles and triangles respectively). Furthermore, the response rate at 1^{c} magnitude changed more than those at 35^{c}. However, the differences between behavior at different reinforcer magnitudes only emerged at the higher reinforcer rates. In addition, the size of the difference was not large.

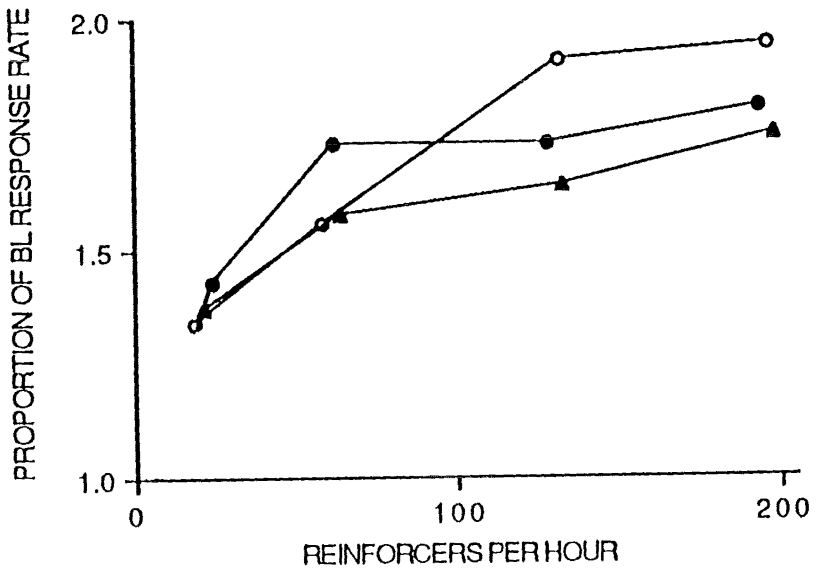

FIGURE 3.3 Group data from McDowell and Wood (1984) with response rates reanalysed in terms of proportion of change from response rate in VI 720. Open circles represent responding at a reinforcer magnitude of .25^{c}, closed circles represent responding at 1^{c} and triangles represent responding at 35^{c}. Proportion of change is plotted as a function of the obtained absolute reinforcer rate (reinforcers per hour).

These results are as expected from Behavioral Momentum Theory. According to Behavioral Momentum Theory the lower mass of behavior in a series using .25^{c} should result in a greater behavior change than behavior supported by the higher mass

establishing condition of 35^{C}. Likewise, behavior at 1^{C} should possess more mass than behavior at $.25^{C}$ but not more than behavior at 35^{C}.

Bradshaw et al (1978) examined the relationship between absolute reinforcer rate and response rate in rats reinforced under different levels of sucrose concentration. Bradshaw et al found that as sucrose concentration increased so did the value of *k* obtained when Equation six was fitted to the data.

For the purpose of reanalysis, response rates were estimated from their graphs (see Appendix I for reanalysed data). The reanalysed data showed that responding did not change by a greater proportion with reduced sucrose concentration (low mass) than with increased sucrose concentration (high mass). These results are inconsistent with the findings of McDowell and Wood but are similar to the lack of trend in the measures of change found in the present experiment. So while predictions from Behavioral Momentum Theory seem to hold up in one case, there is evidence that reinforcer rate change does not always alter responding more in conditions that establish low levels of behavioral mass.

Davison (1988) examined response ratios across two keys in a two-key concurrent schedule as overall reinforcer duration was increased. Each key arranged the same reinforcer rate but the duration of reinforcer delivery on one was 10 seconds and on the other was 3 seconds. Davison found that as overall reinforcer rates increase, the ratio of responding on the two keys was less extreme. Therefore, with increasing reinforcer rate, responding tended not to match the reinforcer ratio of 10:3.

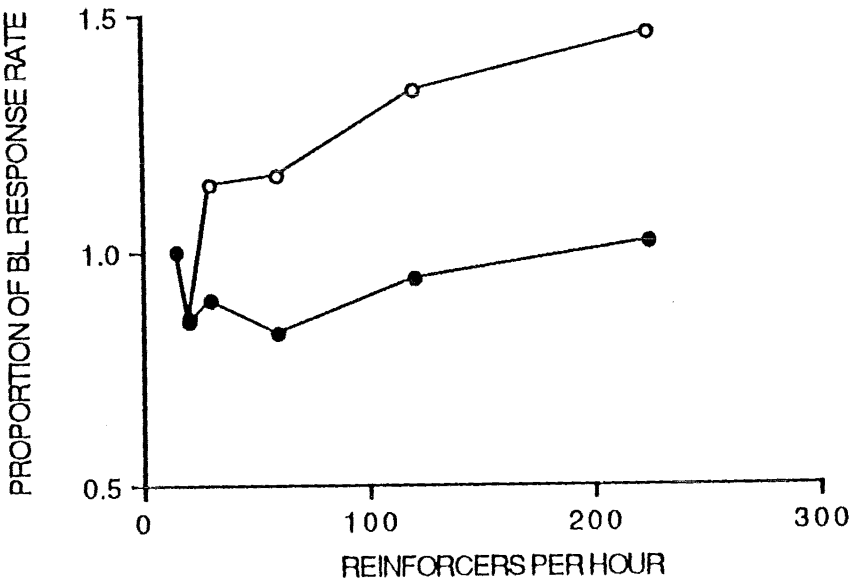

FIGURE 3.4 Group data from Davison (1988) with response rates reanalysed in terms of proportion of change from responding in conc VI 240-sec VI 240-sec. Closed circles represent change in response rates on the key maintained by 10-sec. reinforcers. Open circles represent change in response rates on the key maintained by 3-second reinforcers. Proportions of change are plotted as a function of scheduled absolute reinforcer rates (reinforcers per hour).

Figure 3.4 shows the group data from all six of Davison's birds reanalysed in terms of proportion of change. Using response rates in the lowest reinforcer rate condition (conc

VI 240-sec VI 240-sec) as a baseline allowed a calculation of proportional behavior change at each reinforcer duration across VI schedules. (See Appendix J for reanalysed data). Response rates were the average obtained from the last five sessions of a condition.

The reanalysis of Davison's (1988) data indicated that responding to the shorter reinforcer alternative (open circles) changes more than the responding to the higher duration alternative (closed circles) as reinforcer rate increased.

These results may seem to match predictions from Behavioral Momentum Theory but they are in fact the opposite to what is expected. Resistance-to-change research has tended to use multiple schedules to compare behavior in different mass establishing conditions. Mass is established on responding in the presence of a particular stimulus and is thought to be determined by contingencies between stimuli and reinforcers; not those between responses and reinforcers. In multiple schedules the components are separated temporally and by key colour. In a two-key concurrent schedule the alternatives are usually only separated spatially and most often the keys are the same colour. Therefore, in concurrent schedules the two stimuli presented together can be thought of as combining into one overall stimulus situation in which responding occurs. Accordingly, in a concurrent schedule the conditions establishing mass on one key must also affect the behavioral mass of responding on the other key. That is, responding on each key should possess the same mass. A reanalysis of Davison's data should, according to Behavioral

Momentum Theory, reveal less of a *difference* in resistance to change between components than is the case for multiple or single schedules. In fact Davison's data, unlike the present data, displayed a greater change in responding maintained by short reinforcers than for long reinforcers. The amount of difference in the change shown at each reinforcer duration is also greater in Davison's study than was the case for McDowell and Wood (1984) and for Bradshaw et al (1978).

While group data revealed differences in resistance to change in McDowell and Wood's and Davison's studies, individual subjects displayed great deviation from the group norm in all of the reanalysed studies. It was not until data were grouped did any systematic differences in resistance to change emerge. It is dificult to assert that the differences in resistance to change observed were a robust effect.

The present experiment used a superior method of comparing the proportion of change seen in two behaviors than any of the studies re-examined above, since it ensured that both behaviors being compared occured in any given session. Therefore, the comparisons are relatively uninfluenced by the sort of changes that may have occured between conditions in the single-schedule studies. Furthermore, the multiple-schedule procedure eliminates the possible confounding of mass by concurrent reinforcers arranged on another key. Experiment two convincingly demonstrated that proportion of change does not systematically alter with changes in the reinforcer duration when reinforcer rate change in the maintaining schedule is used as a force.

In conclusion, the present results and reanalyses from

other studies reveals a lack of consistent difference in response rate change under conditions in which behaviors of differental mass are compared. This finding is inconsistent with Behavioral Momentum Theory.

EXPERIMENT THREE

4.1 INTRODUCTION

The focus of Experiment one was to determine whether reinforcer duration acted as a means to establish differences in resistance to change in steady-state responding. Experiment two examined whether a change in the maintaining reinforcer schedule as a force on steady-state responding, produced behavior change consistent with the differences in response mass established by reinforcer duration. The third experiment in the present series examined the effect of differential behavioral mass on the generalised matching relationship. Differential behavioral mass was generated by varing reinforcer duration. Force was applied through variations in the maintaining reinforcer rate.

Reynolds (1963) investigated the relationship between relative reinforcer rate and relative response rate in multiple schedules. Unlike many early studies examining the same relationship in concurrent schedules, Reynold's data did not display strict matching (c.f. Herrnstein, 1961). In general it has been found that the relative response rates in a multiple schedule tend to undermatch, (i.e. are less extreme than), relative reinforcer rates (e.g. Lander & Irwin, 1968; Pliskoff, Shull & Gollub, 1968; Lobb & Davison, 1977; and McLean & White, 1983).

Herrnstein's (1970, 1974) set of equations addressed why behavior displayed less differentiation between two components in a multiple schedule than between two alternatives in a

concurrent schedule. Herrnstein's introduction of the parameter *m* quantified the degree to which the two components interacted (see Equation 8). The greater the value of *m*, the more influence reinforcement in the other component had on responding. However, as shown earlier (see Section 1.2.4) the introduction of *m* into Herrnstein's equation resulted in a logical inconsistency and predictions of multiple-schedule performance that were not supported by the data.

It has been suggested that the strict matching law (upon which Herrstein's equations were based) is a special case of the generalised matching law (e.g. Baum, 1974; and de Villiers, 1977). The greater undermatching found in multiple schedules appears in the generalised matching equation as a low value of the parameter *a* (denoting sensitivity to the reinforcer ratio). One theoretical model of multiple-schedule performance based on the generalised matching equation is that of McLean and White (1983).

Two major differences between the McLean-White model and Herrnstein's were the exclusion of the *m* parameter and the assumption that Ro1 (reinforcement for 'other' behavior in Component 1) was not neccessarily the same as Ro2. McLean and White assumed that the allocation of behavior between B1 and Bo1 depended only upon reinforcement obtained within the component and therefore was insensitive to reinforcement obtained from other components. Taking a generalised matching approach, Herrnstein's (1970) single-schedule equation becomes (for Component one):

$$\frac{B1}{B1 + Bo1} = \frac{R1^a}{R1^a + c \cdot Ro1^a} \qquad \text{Equation 13}$$

In Equation 13, *c* is the inverse of bias between concurrently available alternatives. The parameter *a* is the sensitivity to the concurrent reinforcer rates within Component one. Since *k* (overall behavior in a component) equals B1 + Bo1 then:

$$B1 = \frac{k \cdot R1^a}{R1^a + c \cdot Ro1^a} \qquad \text{Equation 14a}$$

and likewise for Component two:

$$B2 = \frac{k \cdot R2^a}{R2^a + c \cdot Ro2^a} \qquad \text{Equation 14b}$$

By dividing Equation 7a by 7b the ratio B1/B2 can be obtained:

$$\frac{B1}{B2} = (R1/R2)^a \cdot \frac{R2^a + c \cdot Ro2^a}{R1^a + c \cdot Ro1^a} \qquad \text{Equation 15}$$

If Ro1 and Ro2 are kept equal and made large relative to R1 and R2 then Equation 15 tends towards:

$$B1/B2 = (R1/R2)^a \qquad \text{Equation 16}$$

In Equation 16, the parameter *a* represents concurrent-schedule sensitivity. If Ro1 and Ro2 are kept equal and increased relative to R1 and R2 (for example by reducing the level of deprivation), multiple-schedule sensitivity values will increase towards those of

concurrent-schedule sensitivity. Therefore, according to the McLean-White model, multiple-schedule sensitvity is determined by the value of unscheduled concurrently-available reinforcers.

A re-examination of one study that varied deprivation, provides an instance of convergence between the predictions of the McLean-White model and those of Behavioral Momentum Theory. The findings of Herrnstein and Loveland (1974) indicated that two effects of decreasing food deprivation were to: 1) increase the behavioral change shown in a component maintained with a low frequency of reinforcement, and 2) to result in a closer match of the relative reinforcer and response rates. The McLean-White model predicts that as deprivation decreases the relative value of Ro increases, and hence, responding tends towards matching. Behavioral Momentum Theory predicts that as extraneous reinforcers increase in value, the decrease in relative value of the scheduled reinforcers acts as a force to decrease responding. Therefore, it would be expected that as deprivation decreases, the component with the lowest reinforcer rate would change more. Hence, the ratio of B1/B2 would be more extreme with lower deprivation.

The McLean-White (1983) model predicts that if a series of multiple-schedule conditions using a long-reinforcer duration were compared with a similar series using a short duration, then a difference in reinforcer sensitivities would emerge. Ro1 and Ro2 would be larger relative to R1 and R2 in the series with a short-reinforcer duration for the scheduled reinforcers. Therefore, multiple-schedule sensitivity should

be lower for a series of conditions using long-duration reinforcers.

The prediction of lower sensitivity for longer-reinforcer durations can also be derived from Behavioral Momentum Theory. In a two-component multiple schedule, if behavior in both components possesses high mass then the response rate in each component will change less than if both possessed low mass. Since the behavior in both components changes less with an increase in overall mass, the ratio of B1/B2 will be less sensitive to the changes in the ratio R1/R2. Establishing high mass with a longer duration of reinforcement across both components should result in a lower sensitivity to the reinforcer ratio. Changes in the ratio R1/R2 would be acting as a force to change behavior in the two components.

The convergence of predictions between the McLean-White model and Behavioral Momentum Theory point towards an integration of the two notions response strength. Experiment three is an examination of the predictions obtained from both theories when the reinforcer rate ratio is varied at different reinforcer durations.

The force applied to responding in Experiment three (as was the case in Experiment two) was change in the maintaining-reinforcer rate. Given the failure of Experiment two to confirm predictions from Behavioral Momentum Theory the validity of conducting Experiment three may seem questionable. However, the present experiment used different subjects and experimental chambers from Experiments one and two. The procedure of Experiment three was also different from the previous experiments in that reinforcer duration was constant

across components but varied between series of conditions. Furthermore, the results of Experiment three predicted by Behavioral Momentum Theory were also predicted by the McLean-White model.

Studies which have varied the ratios of component reinforcer rates in a multiple schedule have not compared a series of conditions under one common reinforcer duration against the same series of conditions with a different common reinforcer duration (e.g. Nevin & Shettleworth, 1966; Charman & Davison, 1983; McLean & White, 1983; and McLean, 1988). Consequently, the effect of reinforcer duration on the value of *a* (sensitivity to the reinforcer rate ratio) in multiple schedules is not known. Experiment three presented two series of conditions, within which the reinforcer ratio was varied. The only difference between the two series was the reinforcer duration.

4.2 METHOD

4.2.1 Subjects

Four locally obtained homing pigeons with a history of training in multiple schedules were maintained at 80-85% of their free-feeding weight by supplementary feeding. Water and grit were continuously available in the home cages.

4.2.2 Apparatus

Four light-proof sound-attenuating pigeon chambers, 32 cm high, 34 cm deep and 34 cm wide were each fitted with three response keys (21 cm from the floor), a house light and a hopper (6 cm from the floor and directly below the center response key). The house light and the two side keys were never used. The center response key was illuminated either red (S1) or green (S2). Pecks exceeding .15N produced .05 seconds of keylight offset. During reinforcer delivery, the keylight was turned off and the hopper was illuminated in white light. Extraneous sounds were masked by a ventilation fan in each chamber. All experimental events were controlled and recorded by and I.B.M compatible computer running MED-PC Version 4 software.

4.2.3 Procedure

The center key was illuminated red (S1) or green (S2) for 90 second periods in an alternating order. Responses on the center key were reinforced according to Fleshler-Hoffman (1962) VI schedules. The arranged schedule of reinforcement was different for each component and was altered across conditions throughout the experiment.

Experimental condtions were presented in two series. Each pigeon was exposed to both series. The conditons within each series arranged the same changes in reinforcer rate but differed in the duration of reinforcement. When a reinforcer

was delivered during either component in Series one, wheat grain was presented for 2 seconds. When a reinforcer was delivered during either component in Series two, wheat grain was presented for 6 seconds. The stimuli (red in S1 and green in S2) were turned off for the duration of reinforcer presentation. Sessions consisted of 14 presentations of S1 and 14 presentations of S2. The order of conditions each pigeon was exposed to is shown in table 4.1.

Table 4.1

Schedule combinations in each condition (in seconds), order of exposure for each bird, and number of sessions required to reach stability (in parentheses) in Experiment Three.

Schedule Combinations

Condition	*reinf.duration (seconds)*	*S1(red)*	*S2(green)*
1	2	VI 360	VI 60
2	2	VI 60	VI 360
3	2	VI 160	VI 75
4	2	VI 75	VI 160
5	6	VI 360	VI 60
6	6	VI 60	VI 360
7	6	VI 160	VI 75
8	6	VI 75	VI 160

Order of Condition Exposure and Sessions to Stability

Pigeon								
C1	1(30)	3(26)	4(20)	5(20)	7(20)	6(22)	8(21)	5R(20) 6R(25)
C2	4(26)	2(27)	3(34)	1(30)	8(22)	6(25)	7(23)	5(20) 2R(25)
C3	5(27)	7(27)	6(29)	8(21)	1(35)*	3(35)*	2(28)	4(24)
C4	8(27)	6(21)	7(20)	5(25)	4(26)	2(35)*	3(20)	1(35)* 2R(30)

*-Condition terminated before stability criterion reached
R-A repeated condition

The procedure was run seven days a week at approximately the same time every day. For each bird daily sessions were continued within a condition for at least 20 sessions and until a stability criterion had been met. A criterion value was determined by taking the last five successive sessions and calculating for each session: responding in S1 as a proportion of total responding in S1 and S2. The five proportions, thus obtained, were then averaged to give one overall value. The criterion was that each proportion over the last five sessions was not different by +/- .025 from the overall average. This criterion requirement ensured that the relative response rates were stable and not fluctuating extremely from session to session. If a subject failed to meet the criterion after 35 sessions in any condition, it was automatically moved on to the next and the last five sessions data were adopted in any case. Instances where this was the case are indicated with asterisks in Table 4.1.

4.3 Results

The summary response rate data used for analysis in the present experiment were the means from the last five sessions of a condition when behavior was stable according to the criterion. Reinforcer rate means were taken from the last ten sessions of a condition because, particularly at low reinforcer frequencies, there was a large degree of variation in the obtained reinforcer rate. Appendix K gives each bird's mean response and reinforcer rates as well as the log response

and reinforcer ratios in each component for each condition.

Rates were calculated by taking the absolute number of responses or reinforcers in a component and dividing by the time spent responding in that component. The time spent responding in a component was component duration (90 seconds) minus the time in which reinforcers were made available. These measures, therefore, represent the responses emitted in a component relative to time available for responding.

Figure 4.1 shows logarithms of response rate ratios plotted as a function of logarithms of reinforcer rate ratios. Ratios in this figure are rates in S1 divided by rates in S2. The left hand graphs show data from Series one (Conditions 1 - 4) in which the reinforcer duration was 2 seconds. The right hand graphs show data from Series two (Conditions 5 - 8) in which the reinforcer duration was 6 seconds.

Least-squares regression lines were fitted to the data obtained for each pigeon. Equations of the fitted regression lines are given in Table 4.2. Least-squares regression lines correspond to the function given by the logarithmic form of the generalised matching equation (Equation 3). The slopes of these lines provide a measure of multiple-schedule sensitivity. The sensitivity values obtained for the response ratios in Series one (responding under short reinforcers) ranged from .094 to .409. The sensitivity values obtained for the response ratios in Series two (responding under long reinforcers) ranged from -.020 to .441. Sensitivity values tended to be at the lower range of what is normally obtained in multiple schedules. Equation 3 fitted the present data well with low standard error measures for all regression lines.

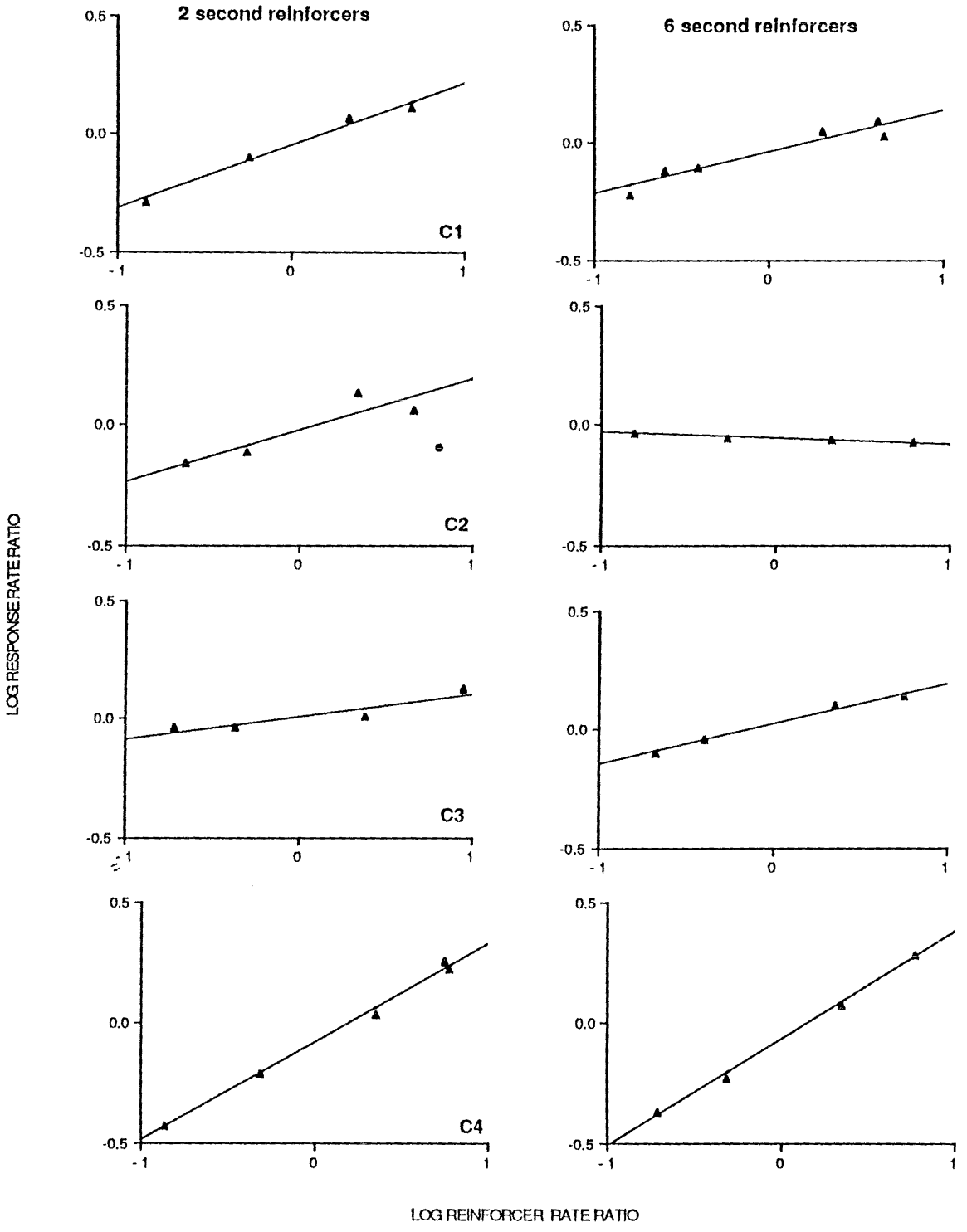

FIGURE 4.1 Log response ratios are plotted against log reinforcer ratios for each pigeon. Left hand graphs show data from Series one, where the duration of reinforcer delivery in both components was 2 seconds. The right hand graphs show data from Series two, where the reinforcer duration was 6 seconds.

Table 4.2

Sensitivity, bias and standard error of estimate measures obtained from regression lines fitted to the data in Experiment three.

Pigeon	*reinf.duration (seconds)*	*bias [log(c)]*	*sensitivity [a]*	*std.error of estimate*
C1	2	-.05	.266	.019
	6	.04	.179	.033
C2	2	.02	.213	.050
	6	-.06	-.020	.003
C3	2	.01	.094	.025
	6	.02	.169	.011
C4	2	-.08	.409	.020
	6	-.07	.441	.013

For Bird C2 the data point denoted by a circle (in Figure 4.1) was obtained when condition two was replicated (mult VI 60-sec VI 360-sec at 2-seconds reinforcer duration), after completion of the series which used long reinforcers. This data point deviated from the others obtained in the series, a matter which will be returned to later (see Section 4.4). The data point was not included in the analysis of sensitivity and bias.

A comparison of the matching line slopes, obtained at 2- and 6-seconds of reinforcer duration, indicted that for Birds C1 and C2, there is a greater sensitivity with 2-second reinforcers than 6-second reinforcers. Bird C3 displayed slightly greater sensitivity for 6-seconds of reinforcer duration, and Bird C4 showed virtually identical sensitivity for 2- and 6-seconds of reinforcer duration. Overall, the data do not indicate any consistent differences in sensitivity

durations.

The intercept of the regression line on the y-axis measures the bias towards responding in one component over the other. Measures of bias tended to be small and not vary in a consistent manner with a change in reinforcer duration.

4.4 DISCUSSION

Experiment three was an examination of the influence of reinforcer duration on response ratio sensitivity to the reinforcer rate ratio. The results indicated that there was no consistent difference between the slopes of the matching lines obtained with 2 seconds versus 6 seconds of reinforcer duration in both components of a multiple schedule. The response rate was not neccessarily more or less sensitive to the reinforcer rate ratio at different durations of reinforcer presentation. The findings are contrary to predictions obtained from Behavioral Momentum Theory and the McLean-White (1983) model of multiple-schedule performance. The prediction arrived at from these two sources was that a higher reinforcer duration would lead to lower sensitivity of response rate ratios to reinforcer rate ratios.

Experiment one demonstrated that a mass diffrential can be established across components using reinforcer duration. The differences observed in resistance to change remained present in steady-state responding. Given that differences to resistance to change (due to reinforcer duration) could be maintained over a number of sessions, it was reasonable to

assume that a condition establishing high overall mass would result in less extreme sensitivity.

One interpretation of the present results is that reinforcer rate change in the maintaining schedule does not act with sufficient force to cause differential effects on the response ratio, irrespective of the method used to establish mass. This possibility is unlikely because several other studies which have varied the maintaining reinforcer rate across components have provided data consistent with predictions from Behavioral Momentum Theory. For example, Charman and Davison (1983) varied deprivation and McLean and White (1983) varied the frequency of concurrently available reinforcers to observe the effect on sensitivity. In both studies, as deprivation decreased or concurrent reinforcers increased, (and thereby, decreased behavioral mass), the ratio of responding became more extreme and tended to match the reinforcer ratio. Reinforcer rate change as a force had effects on sensitivity consistent with the mass established in both components.

The results of Experiment three are compatible with the findings of Experiment two. Experiment two showed that a reinforcer rate change in the maintaining schedule did not result in a greater proportional change for behavior maintained by short duration reinforcers. In the present experiment, as reinforcer duration was decreased there was no increase in the proportional change displayed by responding. Because response rate change was not greater at either 2- or 6-seconds of reinforcer duration the matching functions were similar across the two series.

A possibility for lack of a sensitivity difference due to duration in the present experiment is that behavioral mass became established to such a high level that behavior became insensitive to any changes in the reinforcer conditions. It is possible that mass established by reinforcer duration is cummulative over sessions and eventually reaches a 'saturation point'. The accumulation of mass could have continued across series in the present study. Nevin (1988) noted that it was the stimulus-reinforcer contingency that was important in building up behavioral mass. Nevin (1974 Experiment 5) demonstrated that the response rate did not alter the resistance of change of behavior to a given stimulus. In the present experiment, the stimuli in Series one and Series two were identical. Therefore, the mass built up in one series of conditions may have affected resistance to change in the next series.

One indicator that this may have occured is that the two birds which began training on the short-reinforcer duration series (C1 and C2), were the only two birds to show a flatter function when changed to the high mass series. Because C3 and C4 began under high mass conditions, their responding may have accumulated so much behavioral mass that a reduction in the conditions sustaining mass did not in fact decrease mass by any great extent. These two birds displayed very little differentiation between the low and high mass series.

A second indicator that mass may accumulate is the abnormally low data point obtained by C2 in Figure 4.1. After finishing both series of conditions, C2 repeated Condition 2. Condition 2 was a return to the low mass series after

completion of the high mass series. The low data point indicated that there was little change in response rates in either component from the last condition. This is what would be expected if mass had remained at a high level despite a change to a condition which previously supported a low level of mass. To avoid the possibility of mass accumulating on particular stimuli, it might have been prudent to use different component stimuli in the two series.

Response rate ratios in Experiment three varied in a linear fashion with changes in the reinforcer rate ratio. This finding was consistent with past studies (e.g. Lander & Irwin, 1968; Charman & Davison, 1983; and McLean & White, 1983). However, both the McLean-White (1983) model and Behavioral Momentum Theory failed to predict the finding that sensitivity of the response rate ratios in multiple schedules was not altered by the reinforcer duration. This failure indicates that both theories are either incomplete or simply wrong.

GENERAL DISCUSSION

The experiments conducted in the present study were an attempt to examine the implications of resistance-to-change findings for the response-reinforcer relations specified in the Law of Effect. Studies in the Law of Effect tradition (e.g. Herrnstein, 1961, 1970; and McLean & White, 1983; plus many others) have used response rate as a measure of response strength. Increases in the maintaining reinforcer rate typically increase the response rate, and therefore, responding is said to be strengthened. Studies examining resistance to change (e.g. Nevin, 1974; Nevin et al, 1983 and Fath et al; 1983) have measured response strength as a change in response rate, proportional to baseline, when some external variable is introduced which disrupts responding. The assessment procedure to examine resistance to change makes use of a force (or disruptor) applied to responding via alterations in the reinforcer conditions. Baseline reinforcer conditions establish behavioral mass which creates a resistance to change in the presence of a force.

Both approaches are similar in that they alter the reinforcer conditions to examine how responding consequently changes. The most common method of changing reinforcer conditions in Law of Effect studies has been to alter the maintaining reinforcer rate. Within resistance-to-change research, the most common manipulation of the maintaining reinforcer rate, as a force on responding, has been to change the reinforcer schedules to extinction. However, using extinction as a means to examine resistance to change is

innacurate because of the unequal application of force across different reinforcer rate conditions (see Section 1.3). Consequently, there has been no clear evidence that different behavioral masses of responding affect the relationship between response rate and alterations in the maintaining reinforcer rate in the Law of Effect.

To integrate the two approaches fully, change to the maintaining reinforcer schedule (as a force) needed to be shown to have different effects on responding dependent upon different behavioral masses. Mass differences established by reinforcer frequency are not appropriate for this demonstration because the mass difference is confounded by altering the maintaining reinforcer schedule as a means to apply force. The results of Nevin (1974, Experiment 3) indicated that reinforcer duration had the potential to establish a mass differential across components. The difference in mass, thus created, would not be altered by equal changes in the reinforcer rate for the two responses.

Experiment one determined whether differences in reinforcer duration could act as a means to establish differences in resistance to change that were persistant over time. In most Law of Effect studies, behavior is studied at its steady-state level. That is, conditions of reinforcement are maintained over a large number of sessions until behavior ceases to change. In resistance-to-change research, only short-term disruption to behavior has been applied, and the procedures used by Nevin and colleagues, therefore, have not investigated steady-state responding. However, it is desirable to establish that behavioral phenomena are still

present after many sessions of training. Investigating behavior in the short term does not allow a determination of whether phenomena persist to influence long term behavior because short-term differences may reflect either a different response time of the measured system or alternatively, a different sensitivity.

Experiment one used response-independent food in one multiple-schedule component to disrupt responding in two other components. Reinforcer conditions in the two components, in which responding occured, differed only by the reinforcer duration. Consistent with past research, Experiment one demonstrated that longer reinforcer durations resulted in lower response rate change, measured as a proportion of baseline when response-independent food rate was varied This difference was still clearly present in steady-state responding, achieved after at least 15 sessions with a given response-independent food rate. Reinforcer duration is, therefore, a means to establish persistant differences in resistance to change. In terms of Behavioral Momentum Theory, reinforcer duration is a contributor to behavioral mass.

Experiment one applied force via response-independent food in a third component. Experiment two investigated whether the same differences in behavioral mass between components with long versus short reinforcers would be revealed when the force applied to responding was a change in the maintaining reinforcement schedules in the two components. Experiment two made use of reinforcer duration to establish a constant differential in mass across two components. The constant difference in the conditions establishing mass should

have, as in Experiment one, created constant differences in the resistance to change shown by behaviors in the two components when the equal-valued VI schedules in the two components were varied. This manipulation is similar to the use of extinction in many resistance-to-change studies (e.g. Nevin, 1974 and Nevin et al, 1983), but differs in that a number of problems associated with the use of extinction are eliminated. Specifically, the present procedure made identical changes in the reinforcer rate across two components which differed only by a constant difference in their reinforcer duration. The results indicated that the absolute reinforcer and response rates were related by a hyperbolic function, with an asymptote being reached at higher reinforcer rates. The higher values of k (asymptotic responding) with greater reinforcer duration were consistent with the findings of McDowell and Woods (1984) and Bradshaw et al (1978).

The major finding of Experiment two was that there was no difference in resistance to change between behavior maintained by short-reinforcer durations and that maintained by long-reinforcer durations, when reinforcer rate in the maintaining schedule was varied. This was true early on in a condition (i.e. at the point where behavior is usually studied in resistance-to-change studies) and once behavior had reached stability. Therefore, varying the reinforcer rate in the maintaining schedule did not act to change response rates in a way consistent with the differences in the mass-establishing conditions (i.e. reinforcer duration). The result was unexpected since changing the reinforcer rate in a third component (e.g. Experiment one and Nevin, 1974; Nevin et al,

1983) has effects on responding which is dependent upon the mass establishing conditions.

Experiment three examined the effect of reinforcer duration on the generalised matching relationship (Equation 3). The generalised matching reltionship quantifies the relationship between reinforcer and response ratios in steady state behavior. According to Behavioral Momentum Theory (and Experiment one), a long-reinforcer duration should sustain greater behavioral mass. As mass is increased behavior becomes more resistant to change. Therefore, a change in the reinforcer rate with a long-reinforcer duration will cause less of a change in the response rate (proportional to baseline) than when the reinforcer duration is short. This should be the case for behavior in both components, and should thus affect the extent to which response ratios change.

The parameter *a* in the generalised matching equation quantifies the sensitivity of the response ratio to alterations in the reinforcer ratio. The value of *a* was expected to be lower under conditions of long-reinforcer duration. Behavior at long-reinforcer durations is more resistant to change, therefore, responding in both components should be less sensitive to alterations in the reinforcer ratio.

The procedure of Experiment three was compatible with that of Experiment two. In Experiments two and three, change in the maintaining schedule of reinforcement was the means to exert force on behavior, and differences in reinforcer duration was the means to establish and maintain a mass difference. In Experiment three, a differential in the mass

establishing conditions was arranged between series of conditions instead of between components as in Experiment two.

It may seem strange that Experiment three was conducted at all, given that Experiment two had failed to confirm mass differences due to reinforcer duration when the same 'force' (reinforcer rate change) was applied. There were a number of reasons for running this experiment. First, time constraints on the project as a whole dictated that if Experiment three was going to be run at all, it needed to be commenced at about the same time as Experiment one. That is, when it commenced the results of Experiment two were not known. Second, and more important, there were additional theoretical reasons for expecting reinforcer duration to affect multiple-schedule sensitivity, derived from McLean and Whites' (1983) analysis of multiple-schedule performance. Finally, a third reason for conducting and presenting Experiment three was that it employed new subjects with different experimental histories, new experimental chambers and a new procedure. However, the results of both experiments indicated that variations in the reinforcer rate (or ratio) did not act to change the response rate (or ratio) in a way consistent with differences in the mass establishing conditions; (created by reinforcer duration).

The results of Experiments one and two, which both used the resistance-to-change paradigm can be summarised using behavioral mass ratios. According to Behavioral Momentum Theory, the mass ratio should be constant across all levels of force (Nevin et al, 1983), providing that mass establishing conditions remain constant. Mass ratios are obtained by

dividing the proportional change in one component by the proportional change in the other, and are given in Table 5.1 below for Experiments one and two. In Experiment one the difference in mass establishing conditions was sufficient to produce reliable differences in resistance to change across components. Consequently, the mass ratios in Experiment one were not close to a value of 1.0. A mass ratio of 1.0 indicates that resistance to change was not different across components. In Experiment two, there was idiosyncratyic variation between subjects in the mass ratios obtained at each level of force. Group averages indicated that, unlike Experiment one, the mass ratios were close to a value of 1.0. Therefore, in Experiment two the mass establishing conditions were insufficient to produce a reliable difference in resistance to change. This seems somewhat paradoxical since in both experiments the conditions used to establish a mass differential were identical.

Table 5.1

Mass ratios obtained at different levels of force (reinforcer rate) in Experiments one and two.

Pigeon	*Experiment 1*		*Experiment 2*				
	VT120	*VT30*	*VI40*	*VI60*	*VI90*	*VI240*	*VI480*
C5	.758	.682	-	1.63	-	.88	.72
C6	.886	.739	.93	1.08	1.38	-	1.09
C7	.989	.836	-	.86	-	.92	1.09
C8	.771	.890	-	1.17	.93	1.03	.85
GROUP	.842	.789	-	1.12	.93	.94	.95

What might be the critical difference between Experiment one and Experiments two and three, that determined whether resistance to change was greater in high mass establishing conditions? One posibility has to do with the conditions which exert force. In Experiment one, force was applied by varying reinforcer rate in a temporally distant component from the component in which behavioral mass was established and measured. In Experiments two and three, the conditions establishing mass and exerting force were present in the same maintaining reinforcer schedule. Perhaps within the same reinforcer schedule, the effect of reinforcer rate combines with reinforcer duration in some way which is unspecified by either the Law of Effect or Behavioral Momentum Theory. For example, the force exerted by changing the reinforcer rate may be a product of the reinforcer rate change in combination with the reinforcer duration present in that component. If so, then in Experiment two, where reinforcer duration is unequal across components, the force applied would be unequal across components. Specifically, the higher reinforcer duration in S2 results in a larger force being applied to behavior in that component when reinforcer rate is varied over the same range as in the other component. Likewise, the lower reinforcer duration in S1 results in a smaller application of force on responding. In Experiment three, reinforcer duration was unequal across series. Therefore, the force applied across series may have been unequal.

One of the requirements of examining resistance to change is that force be applied equally across behaviors being compared. Earlier, the use of extinction as a manipulation

was criticised because changing the reinforcer rate to zero in two components which differ by their rate of reinforcement is a greater change for the component arranging the highest reinforcer rate. The present procedure was superior because the only difference between components (in Experiment one) and series (in Experiment two) was reinforcer duration which was not altered by changes in reinforcer frequency. Consequently, an equal change in reinforcer rate could be made across components or series. In the present case, 6-second reinforcers in Component 2 may have generated behavior which had higher mass after all. However, if the force applied to Component 2 behavior was greater than that applied to Component 1, then a differential in resistance to change would not necessarily be observed.

Combining the conditions which exert force (reinforcer rate) and establish mass (reinforcer duration) into one schedule, may result in a force which cannot be applied evenly. Therefore, in Experiments two and three, the effects on behavior of unequal mass establishing conditions may have been counterbalanced by unequal force application. In Experiment one, differences in resistance to change might have emerged because alterations in the reinforcer rate of a temporally distant component did not combine with the reinforcer duration in the maintaining schedule. Hence, the application of force was not confounded by the mass establishing conditions.

A variation of the method used in Experiment one could be used to determine whether force applied via reinforcer rate change is altered as a result of reinforcer duration in the

same schedule. In Experiment one, response-independent food duration in the dark-key period was 3 seconds per delivery. Force was varied by presenting different reinforcer rates in the dark-key component. Thus, the mass establishing conditions were kept separate from the force application. To examine whether reinforcer rate change applies a greater force when reinforcer durations are higher, the reinforcer duration in the dark-key phase can be varied across series within which the reinforcer rate is varied. Unequal reinforcer durations would have to be arranged across components in a multiple-schedule procedure. As noted in Section 3.4, using a concurrent-schedule procedure does not allow one to assert that the mass establishing conditions are in fact different across behavioral alternatives because the mass built up on one key may be a product of all the reinforcement concurrently available. To examine the combined effects of reinforcer rate and duration on behavior that differs by a constant mass difference the multiple-schedule conditions in Table 5.2 could be used.

Table 5.2

Conditions to examine the combined effect of dark-key reinforcer rate and duration acting as a force. (VI schedules are in seconds).

Cond.	*S1 (2sec.duration)*	*S2 (6sec.duration)*	*Dark key schedule(duration)*
1	VI120	VI120	0
2	"	"	VT120(6sec.)
3	"	"	0
4	"	"	VT120(2sec.)
5	"	"	0
6	"	"	VT60(6sec.)
7	"	"	0
8	"	"	VT60(2sec.)

If reinforcer rate change is having a greater effect at longer reinforcer durations, then behavior change will be greater over Conditions 2 and 6 (relative to baseline) than over Conditions 4 and 8.

The present results highlight the need to understand the way in which parameters of reinforcement may possibly interact to produce behavior change. Behavioral Momentum Theory and the Law of Effect both fail to specify that behavior change may rely on not just the manipulation of a single variable (e.g. reinforcer rate) but also its modulation via other variables. Other variables may include reinforcer delay as well as duration. The way in which such variables may interact could well be complex and not easlily encompassed by the current quantitative models. More research needs to be done to investigate this possibility since in most procedures only one aspect of the reinforcer situation is varied at any one time to create a behavior change. Therefore, the combined effect of other variables is held constant.

Compatibility of Law of Effect and resistance-to-change research is possible when the influence of changes in a remote reinforcer rate on responding is examined. For instance Experiment one demonstrated contrast in a component when reinforcer rate was varied in another component. Greater contrast occured when the reinforcer duration was low in the target component. These results were in keeping with Reynolds' (1963) report of greater contrast with increasing overall reinforcer rate. The results of Experiment one were also predicted from Behavioral Momentum Theory and consistent with the McLean-White (1983) model.

A hyperbolic function relating absolute reinforcer and response rates with a variable *k* is consistent with Linear Systems Theory and Herrnstein's equation (without the requirement of a constant *k*). But neither predicts that the data will be more variable at a shorter reinforcer duration. Behavioral Mometum Theory can aid understanding of why, within subjects, hyperbolic functions fitted the absolute response rates better at the longer reinforcer duration in Experiment two. At short reinforcer durations Ro will be relatively more influential on operant responding than at long reinforcer durations. Real Ro can be expected to change from day to day depending upon uncontrolled variables such as time of day that a session was run. Therefore, some days greater force was applied to operant behavior via Ro than on other days. Since Ro is relatively greater for short duration reinforcers - the influence of Ro in disrupting behavior will produce a greater effect on behavior from day to day. From statements of the Law of Effect we expect a hyperbolic function. Behavioral Momentum Theory contributes to the understanding of the function by providing a means to explain why the robustness of the function may be altered by reinforcer duration.

Behavioral Momentum Theory seems incompatible with Law of Effect studies when it comes to predicting concurrent schedule results. Concurrently available reinforcers should add to the mass of behavior. In a concurrent schedule, there is a confounding of the mass built up on each alternative, since the alternatives presented together that constitute a single reinforcer situation. Davison's (1988) data, when reanalysed in terms of proportion of change, showed a greater amount of

change for responding maintained by the shorter reinforcer duration. Individual data were idiosyncratic and this result only emerged convincingly when group data was examined. Therefore, it is doubtful that Davison's data is contrary to that expected in a concurrent schedule.

In Section 4 the McLean-White model was presented as being compatible with Behavioral Momentum Theory when treating concurrent reinforcement as a source of Ro (and hence a force operating on the studied response). The results of McLean and White (1983), however, are not compatible with Behavioral Momentum Theory when concurrent reinforcers are viewed as a contributor to the mass of a component. Behavioral mass is thought to be determined by stimulus-reinforcer, not response-reinforcer contingencies. Consequently, right-key reinforcers in McLean and White (Experiment one) should increase the mass of both left- and right-key behavior. McLean and White demonstrated that with a high concurrent reinforcer rate, high multiple-schedule sensitivity resulted. If concurrent reinforcement adds to to a components' behavioral mass then the component associated with highest concurrent reinforcer rate would possess greater mass. Greater mass should result in behavior in that component that is more resistant to change. Resultingly, high concurrent reinforcement, if viewed this way, should result in lower sensitivity since behavior will not readily change with alterations in the component reinforcer rate ratio.

Behavioral Momentum Theory is incomplete, because of the different possible interpretations that the effect of concurrent reinforcement can have on resistance to change.

Concurrent reinforcers may be acting as a force, a contributor to mass or both. The extent to which concurrent reinforcers contribute to mass and force needs to be determined since concurrent reinforcers are always present in the form of extraneous reinforcers in a multiple-schedule procedure. Furthermore, the extent to which extraneous reinforcers are reallocable will alter the contribution to mass by concurrent reinforcement.

It appears that research has not pinned down precisely the variables and their interactions that contribute to response strength. The implications of resistance to change created by behavioral mass for the reinforcer-response relationships described by the Law of Effect are difficult to establish because both approaches fail to account for all the present findings. There may be a great deal of compatibility between measures of strength but the conditions that alter those measures have not been fully determined. Consequently, any compatibility of using response rate and proportion of baseline responding may be due solely to them both being erroneous ways to measure behavioral strength.

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APPENDICES

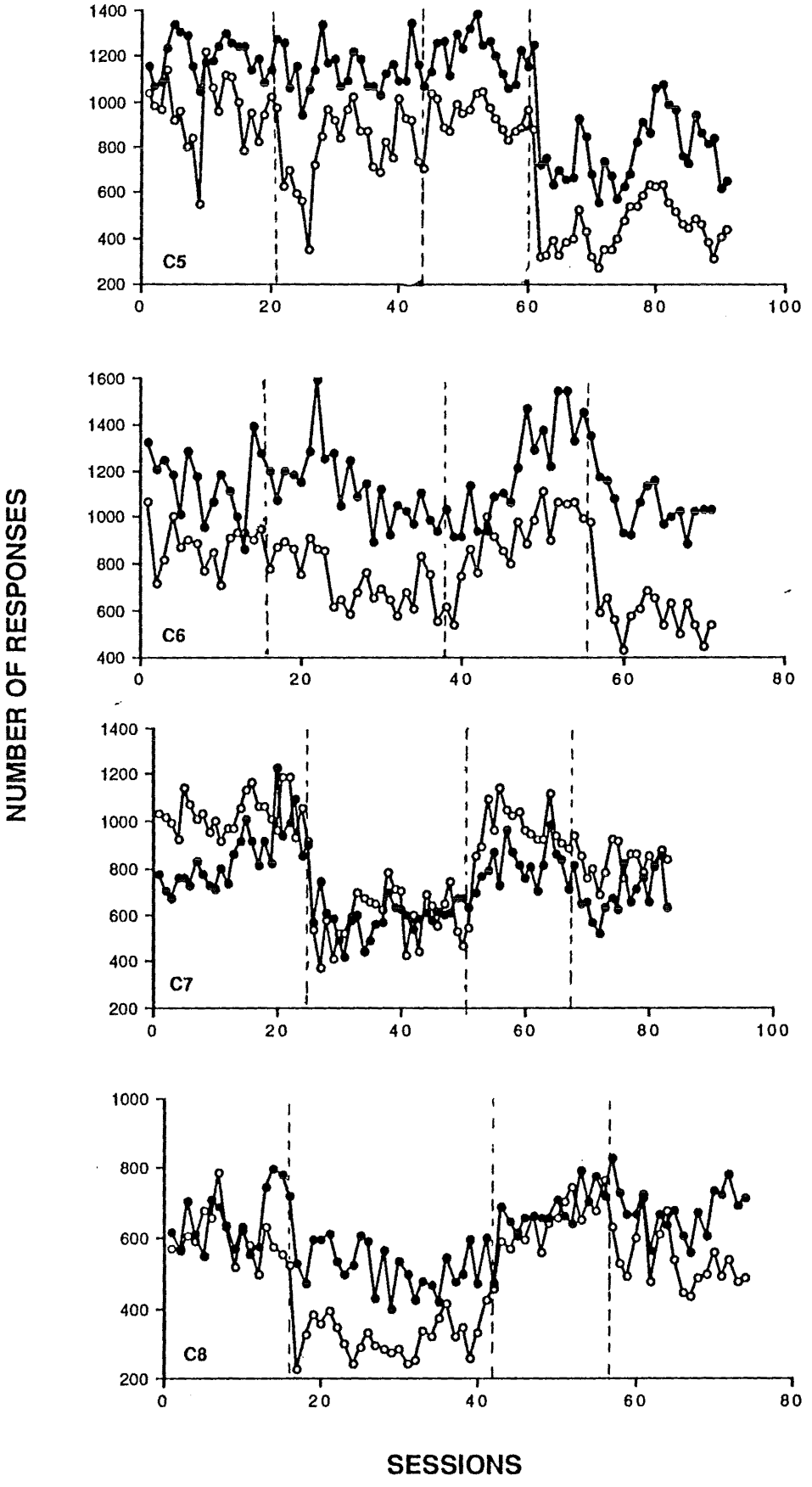
APPENDIX A

Program for Calculating Absolute Response Rate Stability

```
10 HOME
12 INPUT "RESPONSE RATE FROM LAST 9 DAYS??";R(1);R(2);R(3);
   R(4);R(5);R(6);R(7);R(8);R(9)
20 FOR I=1 TO 5
30 FOR J=1 TO I + 4
50 X(I) = X(I) + R(J)
60 NEXT J
70 Y(I) = X(I)/5 : PRINT Y(I)
80 NEXT I
90 FOR Z=1 TO 9
100 T=T + R(Z)
110 NEXT Z
120 AV=T/9
130 LCL=AV - (AV*.075): UCL+AV + (AV*.075)
135 PRINT "AVERAGE=";AV
136 PRINT "C.I.";"=";LCL;"-";UCL
140 FOR I=1 TO 5
150 IF Y(I)<LCL THEN GOTO 200
160 IF Y(I)>UCL THEN GOTO 200
170 NEXT I
180 PRINT "STABLE!!"
190 GOTO 205
200 PRINT "NOT STABLE"
205 CLEAR
210 INPUT "ANY MORE (Y OR N - PRESS RETURN)";ANS$
220 IF ANS$="Y" THEN GOTO 10
230 HOME
```

APPENDIX B

Graph of Raw Data in Experiment One
(dotted lines indicate a change in condition).



APPENDIX C

Reinforcer and response rates in Experiment one gained from the average of the initial and last five sessions in a condition. S1=2 and S2=6 seconds of reinforcer duration.

	dark-key reinf.per hr initial/final		*baseline ave.no.of responses (S1)*	*(S2)*	*average no. of responses initial sessions (S1)*	*(S2)*	*final sessions (S1)*	*(S2)*
C6	25.8	33.2	943	1164	565	1095	860	1385
	127.4	123.7	885	1155	349	694	398	757
C6	33.2	25.8	899	1145	859	1176	705	1012
	117	124.6	1036	1445	565	1054	533	1001
C7	30.5	24.9	957	841	774	605	830	738
	127.4	124.6	1054	954	483	598	586	635
C8	32.3	23.1	687	764	561	671	510	730
	124.6	124.6	555	724	335	560	362	527

Proportion of Baseline Response Rate Change in Experiment One.

	initial 5 sessions				*final 5 sessions*			
	VT 120		*VT 30*		*VT 120*		*VT 30*	
Bird	*(S1)*	*(S2)*	*(S1)*	*(S2)*	*(S1)*	*(S2)*	*(S1)*	*(S2)*
C5	.6	.94	.91	1.2	.4	.6	.45	.66
C6	.96	1.03	.78	.88	.55	.73	.51	.69
C7	.81	.72	.87	.88	.46	.63	.56	.67
C8	.82	.88	.74	.96	.6	.77	.65	.73

APPENDIX D

Absolute response rates in initial 5 sessions per condition of Experiment 2. S1=2 and S2=6 seconds of reinforcer duration.

Pigeon	*Condition*	*resp.per min* *S1*	*S2*	*reinf.per hour* *S1*	*S2*
C5	3	50.64	101.22	53.54	58.31
	2*	54.03	88.96	27.27	26.68
	4	42.72	89.87	9.19	12.84
	5	49.96	79.94	10.34	14.04
C6	6	41.96	107.3	80.60	82.56
	3	30.75	96.50	46.91	58.31
	1	49.61	97.11	37.93	40.24
	2*	37.28	88.42	27.07	28.12
	5	31.95	83.44	5.73	5.77
C7	3	57.90	71.49	58.41	57.62
	2*	57.03	60.38	26.87	27.91
	4	61.81	59.00	13.82	12.24
	5	58.07	61.84	7.46	6.35
C8	3	43.40	51.42	57.19	52.85
	1	36.48	51.96	36.73	42.20
	2*	39.64	51.65	25.50	27.08
	4	41.57	50.33	16.73	12.84
	5	29.09	43.53	5.73	11.65
GROUP	3	45.67	80.16	54.01	56.77
	2*	47.00	72.35	26.68	27.45
	4	48.70	66.40	13.25	12.64
	5	42.27	67.19	7.32	9.45

* response and reinforcer rates given here are the average of all repeats of this condition.

APPENDIX E

Response Rates in Final 5 Sessions per Condition of Experiment 2. S1=2 and S2=6 seconds of reinforcer duration.

Pigeon	*Condition*	*resp.per min* S1	S2	*reinf.per hour* S1	S2
C5	3	64.72	93.83	52.98	57.37
	2*	51.92	89.16	25.39	27.64
	4	44.80	78.96	15.27	14.69
	5	34.58	73.59	6.60	9.28
C6	6	36.34	110.84	77.48	79.98
	3	32.62	102.34	50.59	60.56
	1	43.74	97.52	37.61	41.51
	2*	31.33	97.22	25.47	26.99
	5	23.15	65.51	6.31	6.66
C7	3	54.23	68.27	54.15	58.31
	2*	64.64	69.01	25.58	27.41
	4	51.28	58.84	12.96	15.85
	5	53.18	51.70	9.78	7.52
C8	3	48.03	53.25	60.91	61.14
	1	40.15	57.01	38.19	38.64
	2*	40.84	51.68	27.07	27.00
	4	37.13	47.48	14.97	13.98
	5	32.07	44.33	8.04	7.52
GROUP	3	49.90	79.42	54.66	59.35
	2*	47.18	76.77	25.88	27.26*
	4	44.40	61.76	14.40	14.84
	5	35.75	58.78	7.68	7.75

* response and reinforcer rates given here are the average of all repeats of this condition.

APPENDIX F

Response rates in the final five sessions of baseline conditions (Condition 2) in Experiment two. S1=2 and S2=6 seconds of reinforcer duration.

Bird	*baseline for Condition #:*	*responses per minute S1*	*S2*	*reinforcers per hour S1*	*S2*
C5	3	34.69	81.59	25.48	26.54
	4	63.22	97.77	24.01	28.26
	5	57.86	88.12	26.68	28.12
C6	1	32.51	100.64	25.77	27.76
	3	29.01	98.50	24.26	26.02
	5	32.51	100.64	25.77	27.76
	6	32.48	92.53	26.39	27.19
C7	3	63.07	68.04	24.58	24.68
	4	62.84	66.64	25.81	28.17
	5	68.00	72.34	26.35	29.37
C8	1	41.35	54.42	27.87	26.24
	3	44.45	57.49	27.24	25.52
	4	41.35	54.42	27.87	26.24
	5	36.72	43.12	26.10	29.25
GROUP	3	42.81	76.41	25.39	25.69
	4	55.80	72.94	25.90	27.56
	5	48.77	76.06	26.23	28.63

APPENDIX G

Proportion of baseline response rate in Experiment two (calculated by dividing absolute response rates in Appendices D & E by baseline response rates in Appendix F). S1=2 and S2=6 seconds of reinforcer duration.

Pigeon/ Condition (in seconds)			*initial 5 sessions*		*final 5 sessions*	
			S1	*S2*	*S1*	*S2*
C5	3	VI 60 VI 60	1.46	1.24	1.87	1.15
	4	VI 240 VI 240	.676	.920	.708	.808
	5	VI 480 VI 480	.863	.907	.598	.835
C6	6	VI 40 VI 40	1.29	1.16	1.12	1.20
	3	VI 60 VI 60	1.06	.980	1.12	1.04
	1	VI 90 VI 90	1.53	.965	1.35	.969
	5	VI 480 VI 480	.980	.829	.712	.651
C7	3	VI 60 VI 60	.918	1.05	.860	1.00
	4	VI 240 VI 240	.984	.885	.816	.883
	5	VI 480 VI 480	.854	.855	.782	.715
C8	3	VI 60 VI 60	.976	.894	1.08	.926
	1	VI 90 VI 90	.882	.955	.971	1.05
	4	VI 240 VI 240	1.01	.925	.898	.872
	5	VI 480 VI 480	.792	1.01	.873	1.03
GRP	3	VI 60 VI 60	1.07	1.05	1.17	1.04
	4	VI 240 VI 240	.873	.910	.796	.847
	5	VI 480 VI 480	.867	.883	.733	.773

APPENDIX H

McDowell and Wood (1984) reanalysed in terms of proportion of change as a function of reinforcer magnitude.

Subject/ Condition (in seconds)		*reinforcer magnitude (cents) .25*	*1*	*35*
H09	VI 720	1	1	1
	VI 157	1.49	1.66	1.46
	VI 51	1.94	2.49	1.85
	VI 25	-	2.36	2.12
	VI 17	-	2.56	2.39
H15	VI 720	1	1	1
	VI 157	1.00	1.03	1.03
	VI 51	1.11	1.09	1.08
	VI 25	1.08	1.08	1.03
	VI 17	1.12	1.14	1.11
H17	VI 720	1	1	1
	VI 157	3.59	4.74	3.22
	VI 51	4.36	5.97	3.94
	VI 25	4.56	6.45	4.04
	VI 17	4.42	6.40	3.92
GROUP	VI 720	1	1	1
	VI 157	1.34	1.43	1.37
	VI 51	1.56	1.73	1.58
	VI 25	1.91	1.73	1.64
	VI 17	1.94	1.81	1.75

N.B. VI720 was used as the baseline condition to measure proportion of change. The subjects used for reanalysis were the only ones that receieved the above conditions.

APPENDIX I

Group data from Bradshaw et al (1978) reanalysed in terms of proportional response rate change between the highest and lowest reinforcer rate.

reinforcer magnitude(M) -sucrose	*Responding in the highest reinforcer rate cond. as a proportion of responding in the lowest*
0.0	2.63
0.05	2.30
0.32	2.70

APPENDIX J

Reanalysis of Davison (1988) in terms of proportion of change in two alternatives of a concurrent schedule as a function of reinforcer duration.

Subject/ Condition(sec)	*reinforcer duration(seconds) S1=10s*	*S2=3s*
21 VI 240 VI 240	1	1
VI 180 VI 180	1.10	1.00
VI 120 VI 120	0.89	1.22
VI 60 VI 60	0.79	1.27
VI 30 VI 30	0.71	1.00
VI 16 VI 16	0.85	1.20
22 VI 240 VI 240	1	1
VI 180 VI 180	0.73	0.57
VI 120 VI 120	1.00	1.08
VI 60 VI 60	0.31	0.42
VI 30 VI 30	0.87	1.19
VI 16 VI 16	0.87	1.05
23 VI 240 VI 240	1	1
VI 180 VI 180	1.08	1.25
VI 120 VI 120	1.01	1.32
VI 60 VI 60	1.23	1.49
VI 30 VI 30	1.52	1.72
VI 16 VI 16	1.18	3.43
24 VI 240 VI 240	1	1
VI 180 VI 180	1.13	1.29
VI 120 VI 120	1.82	1.47
VI 60 VI 60	1.21	2.42
VI 30 VI 30	1.02	3.11
VI 16 VI 16	1.26	3.54
25 VI 240 VI 240	1	1
VI 180 VI 180	0.70	0.98
VI 120 VI 120	0.57	1.03
VI 60 VI 60	0.91	1.67
VI 30 VI 30	0.80	1.57
VI 16 VI 16	1.19	1.28
26 VI 240 VI 240	1	1
VI 180 VI 180	0.75	0.97
VI 120 VI 120	0.84	1.41
VI 60 VI 60	1.05	1.26
VI 30 VI 30	1.02	0.94
VI 16 VI 16	1.00	1.27
27 VI 240 VI 240	1	1
VI 180 VI 180	0.85	0.86
VI 120 VI 120	0.90	1.14
VI 60 VI 60	0.83	1.16
VI 30 VI 30	0.94	1.34
VI 16 VI 16	1.02	1.46

N.B. Conditions used for reanalysis were ones where S1=10sec and S2=3sec.

APPENDIX K

Response and reinforcer rate ratios from the final 5 sessions in a condition in Experiment three.

Series one - 2 second reinforcer duration in S1 and S2:

Pigeon	*response rate(per min.)*			*reinforcer rate(per hour)*		
	S1	*S2*	*log.ratio*	*S1*	*S2*	*log.ratio*
C1	45.05	86.83	-.285	7.73	2.99	-.836
	84.42	65.15	.112	52.99	10.63	.689
	67.39	85.48	-.103	23.16	40.63	-.244
	80.73	69.55	.065	42.69	19.65	.337
C2	37.28	53.71	-.159	11.78	53.05	-.654
	32.65	28.19	.064	53.17	11.77	.655
	43.37	56.36	-.114	21.39	43.36	-.307
	45.56	33.79	.130	43.29	19.92	.337
	44.23	55.11	-.095	56.58	8.90	.803
C3	64.60	70.28	-.037	10.64	55.64	-.718
	95.75	71.97	.124	55.75	6.31	.947
	70.13	76.60	-.038	18.47	42.97	-.367
	80.03	78.34	.009	47.51	19.93	.377
C4	17.77	47.50	-.427	7.47	54.34	-.862
	50.46	27.91	.257	56.31	10.07	.747
	28.79	46.80	-.211	20.51	42.43	-.316
	39.15	35.99	.037	43.62	19.36	.353
	45.90	27.54	.222	54.76	9.19	.775

Series two - 6 second reinforcer duration in S1 and S2:

Pigeon	*response rate(per min.)*			*reinforcer rate(per hour)*		
	S1	*S2*	*log.ratio*	*S1*	*S2*	*log.ratio*
C1	78.41	102.64	-.117	13.80	54.18	-.594
	82.55	77.33	.028	58.93	12.94	.658
	67.85	86.27	-.104	18.31	46.85	-.408
	83.87	75.40	.046	47.64	23.62	.304
	59.93	99.93	-.222	8.74	54.46	-.795
	78.00	63.16	.092	58.31	14.04	.619
C2	50.00	54.07	-.034	9.32	60.06	-.809
	40.49	48.04	-.074	61.07	10.14	.780
	53.44	60.32	-.053	24.24	45.94	-.278
	49.22	56.50	-.060	46.30	22.19	.319
C3	61.09	76.30	-.097	11.84	55.76	-.673
	87.79	64.00	.137	59.05	10.44	.752
	61.86	68.61	-.045	20.43	50.98	-.397
	63.36	50.41	.099	47.29	20.94	.354
C4	23.04	53.75	-.368	11.39	58.38	-.710
	58.78	31.01	.278	55.68	9.55	.766
	30.96	52.12	-.226	23.47	48.72	-.317
	59.29	50.08	.073	50.26	23.10	.338